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GEOPHYSICS

A Journal of General and Applied Geophysics

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CONTENTS

Geophysics Looks Forward	*R. D. Wyckoff*	287
The Geophysical History of the Cayuga Field, Anderson County, Texas	*H. B. Peacock*	299
Wavelet Functions and Their Polynomials	*Norman Ricker*	314
Geophysical Survey of the Arkansas Bauxite Region	*Mark C. Malamphy and James L. Vallely*	324
Analytical and Experimental Data Concerning a Solid Hydrocarbon Survey of the Fort Collins Anticline	*R. Maurice Tripp*	367
Patents Vested in the Alien Property Custodian	*O. F. Ritzmann*	388
Patents		402
Discussion and Communications		408
Publications Received		409
Memorial		
Lovic Pierce Garrett	*Paul Weaver*	411
Contributors		413
The Society Round Table		
Membership Applications Approved for Publication		415
Fourteenth Annual Meeting of the Society		416
Members Registered at the Fourteenth Annual Meeting		417
Papers Presented or Read by Title at the Technical Sessions		419
Minutes of the Annual Business Meeting		421
Officers for the Year Ending April 1945		422
Ballot on Editor's Term of Office		423
Annual Report of the Secretary-Treasurer		423
Personal Items		426

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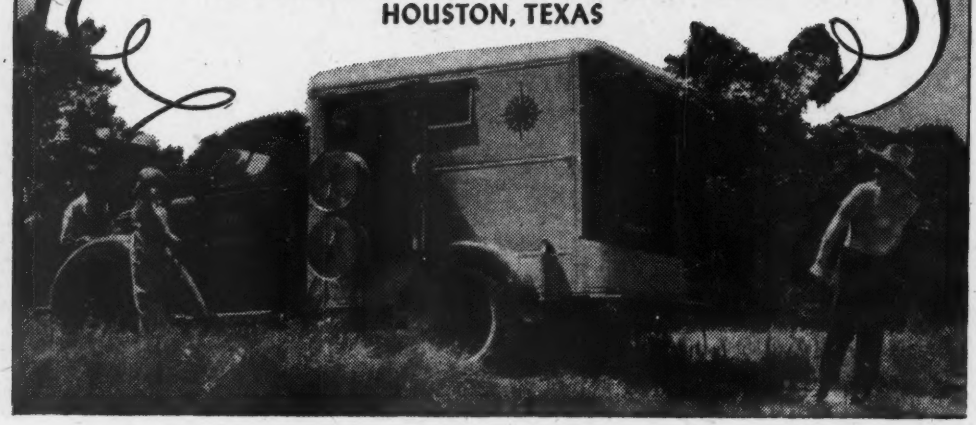


VOLUME IX JULY, 1944 NUMBER 3

GEOPHYSICS

A Journal of General and Applied Geophysics

GEOPHYSICS LOOKS FORWARD*

R. D. WYCKOFF†

We speak of the war emergency and what it has done to our domestic oil reserves. I would not attempt to minimize the effects of the war demand upon our current production facilities nor imply that the extra demand, the purely military consumption, is a minor quantity. But considered in the light of the total quantity of oil that has been taken from the ground in the past and that which is to be added to the grand total by future production, it does not loom out of all proportion as some current discussion would imply. Rather it appears as the warning that has jarred us out of our normal complacency and into an admission that, after all, our domestic oil is limited, that it is being depleted at an alarming pace, and that new reserves are not forthcoming in the accustomed manner at a rate sufficient to replenish the reservoir.

These circumstances were quite clearly indicated before the war and its impact merely brought them further into the open. Additionally, and more significant perhaps, it has doubtless resulted in the revision of our concepts as to the normal future demand. One cannot contemplate modern mechanized war without realizing that at its conclusion the normal accelerated consumption of petroleum resources will accelerate even more rapidly. It is little wonder, therefore, that exploration has suddenly emerged as the bottleneck of our domestic petroleum industry. It is implied that our methods are inadequate; that perhaps they are antiquated and have not kept pace with other technological developments.

* Retiring Presidential Address, Joint Annual Meeting of the Society of Exploration Geophysicists, the American Association of Petroleum Geologists, and the Society of Economic Paleontologists and Mineralogists, Dallas, Texas, March 22, 1944.

† Gulf Research & Development Company, Pittsburgh, Pennsylvania.

Considering the record of recent years—the declining rate in total volume of oil discovered—one must admit a widening gap between added reserves and ever-mounting depletion rates. Judged in the light of actual numbers of new reservoirs, however, one cannot say that exploration, or even in particular that geophysical exploration, has failed, or is now failing in its job. Geophysical methods, like most geological methods, find structure, not oil, and from a technical viewpoint must be judged accordingly. Given virgin territory in which to operate, modern and properly executed exploration methods, including geophysics, have not failed to bring results measuring up to modern technological standards.

It must be remembered that a large proportion of our domestic exploration has been in areas thoroughly combed in the past and that a rework job by any exploration method is still a rework job, carrying the inevitable penalty of diminishing returns. Also it must be considered that much of the domestic work that has been done in virgin territory is either marginally prospective or as yet has been inadequately tested. Bearing in mind these facts much of the criticism aimed at geophysics is totally unwarranted. The point to be emphasized is not the failure of techniques but rather that the job at hand requires methods verging on the occult, the "black magic of the doodle bug."

But while such considerations may be a much needed sop to our vanity, they do not alter the fact that in view of such circumstances our methods are indeed inadequate. Admittedly, in areas that have been subjected to such intense and long continued exploitation as has marked our domestic petroleum industry, no exploration method can be called good enough until it is capable of locating literally the last drop of oil hidden in the subsurface. This of course is an impossible attainment; it serves only to indicate the ultimate goal and to pose the question as to how we may make even a tentative approach to that goal with a minimum of delay. This is the question I wish to discuss.

Apparently it is frankly admitted that our problem is to find *oil*, not merely *prospects*, and particularly not just prospects in the form of structural indications for which we now have finding tools. We are told that the bulk of future domestic reserves probably lies in stratigraphic or even lithologic traps and that it is up to the exploration department to find such oil. Since we are to be so utterly practical in our statement of the problem let us be equally realistic in our approach to the solution. The direct approach is of course the obvious one. Merely design instruments capable of detecting oil directly, and at

once our problem is solved. And this evidently is the nature of the solution most frequently proposed by those who are not charged directly with the technologic development problem. It is not a bad star at which to aim. To dream and plan realistically for the future is both good and necessary, but to indulge in star gazing, particularly through the wrong end of a telescope, is an extravagance which no industry can afford.

Let me digress a moment to illustrate what I mean by this apparently facetious remark. I wish to take cognizance of certain ideas that are springing up in various quarters as a result of the gradual release of information concerning innumerable new "gadgets" of war. Some of these methods and devices are indeed almost magical in their performance and even to those familiar with the technical details of their construction and operation, their performance is almost incredible. It is not surprising, therefore, that in these days the impossible appears as a commonplace accomplishment and that in some quarters of the petroleum industry has arisen the idea that perhaps out of the war will come the long-sought magic needed by their geophysicists. In order to make a realistic approach to our exploration problem I wish first of all to eliminate these delusions.

I hope it will not be considered impertinent to remark here that in proportion to the numbers engaged, geophysicists themselves have contributed no small share in some of these war developments. Some of their contributions have been in the application of geophysical principles, techniques, or instrumental components. Others have contributed their training and applied it to developments totally foreign to geophysics. I mention this not as a reminder of the geophysicists' contribution to the war effort, but merely to emphasize that if new methods are to come out of the war, you may be assured that you have competent representatives on the ground who will be quick to evaluate new developments in the light of geophysical needs and appropriate them for such use.

But with full recognition of the fallability of predictions I venture to say that when the books are balanced, geophysics will have contributed more to the war effort, directly or indirectly, than war developments will have to offer geophysics. I do not mean that we will not be ahead by available improvements in instrumentation, though a portion of such gains will only serve to compensate for the large scale curtailment in geophysical research resulting from the diversion of men and facilities to war developments. Indeed, we are certain to

profit by the enormously accelerated pace of research in all lines. But other than such obvious gains as in improved instrumentation which inevitably results in an improvement in performance, I see no possibilities of major changes. No new geophysical *methods* will come out of the war.

Let me illustrate briefly with one development that seems to have captured the imagination of the layman and thus has given rise to the wildest of dreams. *Radar* is an outstanding war baby, not only in the magnificent details of its conception and development but in its astounding performance. Radio in its simplest form must appear as a miracle to the lay mind and in its more complex aspects looks almost magical even to the initiated. Little wonder, therefore, that a device capable of "seeing" the invisible appears to the uninitiated as the long-sought answer to the geophysicists' prayers.

But the principle of Radar is not new, it is the instrumentation that is new and has made possible its development. It is reflection-radio made possible by the requirements of war and rapid strides in electronics. It is, let us say, analogous to the reflection-seismograph which after early failures eventually emerged from the refraction seismograph much as Radar developed from previously well known radio phenomena. But the analogy goes further. The reflection seismograph is actually "radar" in principle except that elastic waves are used instead of electromagnetic waves because elastic waves will penetrate the earth to useful distances and radar electromagnetic waves will not. One might suggest the use of lower frequencies that will permit greater penetrations and then we see that we are back to the almost endless variations in electrical prospecting methods that have been used by geophysicists for years and are still the subject of experiments in the hope of providing a tool whereby oil, not structure alone, might be found directly. Geophysicsts are well aware of these facts but not so all members of the oil fraternity. I regret the necessity of being realistic but I repeat: it is quite safe to say that no new geophysical *principles* will be found among the war babies.

Doubtless this may sound like the ultimate in pessimism and you may call it that if you wish but I am not one who believes that accomplishments come in on a hope and a prayer. Sometimes we do have luck and results exceed expectations but behind such spectacular events are always the long and tedious efforts on the part of some realists working toward improvements with the methods and tools at hand. And so with geophysics. It made spectacular advances in the

early days while new principles—new to geophysics but old to science —were available and could be brought to bear on the problems. This does not mean that we are now in the process of stagnation but rather that we should not delude ourselves in the belief that there is magic to be pulled out of the hat. Geophysics as a science is old enough to be beyond that stage. We must now work harder for smaller gains, making use of new tools, new instrumentation borrowed from other fields, and this process is usually a slow one devoid of spectacular events.

If this is truly the situation and we are to be realistic about it, where then is the solution? Perhaps it is pertinent at this point to consider the problems presented and to review briefly the methods used thus far in their solution. By so doing, we should be able to gain a more rational viewpoint on the problem.

Orthodox geophysical methods, as now generally practiced, operate on either of two fundamental principles:

(1) Forces having their origin in subsurface anomalies are observed at the surface.

(2) The subsurface is probed in such a manner as to permit mapping the attitude of certain discontinuities which are stratigraphic markers or related to such geologically significant markers.

In the first category—those methods involving the measurement of forces at a distance—we have only two choices, for other than gravitational effects produced by density contrasts, or magnetic effects resulting from non-uniform magnetic properties, we have no operating principle available. Making use of these effects—the only available physical principles—are the two oldest tools of geophysics, the gravimetric and the magnetic methods. It is unnecessary to discuss in detail the type of results obtained. By their very principle of operation it is evident that the geologic implications derived from a study of either type of data, must in general, be indirect and inferential in nature. For except in very special cases, unique solutions of such data are, and must remain, quite impossible. Moreover, it is to be noted that at best such inferential information can pertain only to major anomalies or structures and except for extremely shallow features of little interest in petroleum exploration there is little hope of delineating stratigraphic or lithologic traps.

Both magnetic and gravimetric methods have been, and will continue to be, useful as reconnaissance tools. Actually their effectiveness

has been increased in recent years through the application of more enlightened methods of interpretation. Moreover, the advances in interpretational techniques have been made possible through a simultaneous increase in both the accuracy of the data and the amount of detail secured. This in turn has been possible because of improved instrumentation responsible for the higher accuracy as well as lower operating costs. We may ask how much further improvement may be expected in these reconnaissance tools.

In regard to gravimetric methods a very great stride was made by the development of practical gravimeters. But modern gravimeters have already reached the point where the accuracy of observation exceeds the "noise level." By that is meant that the instruments are already capable of such precision that extraneous, purely local disturbances, produce gravity effects within range of modern field observations. Clearly there is no substantial justification in striving for increased instrumental sensitivity.

However, the interpreter is reasonable in demanding more and more detail since the quality of his inferences is directly affected by the amount of data available in a given area. More data calls for greater expenditures in field surveys or else a speeding up of observations. Already the gravimeter is capable of such operational speeds that the most time-consuming job is that of transportation. Moreover, strange as it may seem, the cost of an accurate gravity survey lies principally in the topographic survey, not the gravity observations. There is, of course, room for improvement in the portability and rugged reliability of gravimetric instruments in order to facilitate field handling. But there is more to be gained by some improvement in topographic survey methods whereby the overall cost of precision gravimetric observations may be most effectively reduced and thus provide the interpreter with more detailed information. These are problems in instrumentation which conceivably can improve current practice but they will not produce any radical changes in overall results.

The magnetic method has been in somewhat less favor than the gravimetric method as a reconnaissance tool. As a petroleum exploration method there may be some justification for this viewpoint although with modern interpretation technique applied to field data of sufficient detail and accuracy, it has definite usefulness. Whether due to lack of impetus arising from this general apathy towards the method or to the lack of technical means for necessary improvement, it is

true that the magnetometer as an instrument has not kept pace with the gravimeter. While existing instruments are capable of a precision within the "noise level," in general they are not so operated. However, it may be said that there are definitely on the horizon improvements in magnetic instrumentation that would enhance the capabilities of the magnetometer. If justified by the demand such improvements will be made, but again they will present an improved reconnaissance method, not a radically new oil-finding tool.

With this hasty disposal of the available methods based on so-called "action at a distance" let us examine the second category of geophysical principles; those methods involving the use of probe phenomena. And while the most direct and perhaps most completely satisfying method is the use of the drill with either direct geological examination of cores or cuttings to obtain the desired subsurface information, or various geophysical methods such as electrical, radioactive, or related logging tools to aid in correlation from well to well, the probe phenomena referred to at the moment is the use of energy applied at the surface and propagated through the subsurface to replace the physical contact of the drill. Indeed, energy propagation alone can be the nature of the intangible probe required and having so specified it, simple physical principles immediately limit our choice to the use of wave energy which may be either electromagnetic or elastic in nature.

Some mention has already been made of the electromagnetic wave methods and the fact that the electrical properties of the subsurface preclude the use of high-frequency phenomena. We have seen that the practical electromagnetic methods involve only very low frequencies which for maximum penetrations degenerate into essentially direct current phenomena. Thus, the electromagnetic methods comprise the already well known electrical prospecting methods which have been extensively exploited and are still the subject of extensive research. I am not prepared to say that greater success than evident in the past will attend the application of electrical methods in the future. But one thing may be said with confidence; radio-frequency phenomena will not be applicable to oil-finding.

We have left elastic-wave energy as the second and to date the most useful method of probing the subsurface. As in the case of electromagnetic energy, we are dependent upon more or less abrupt discontinuities in the propagation constants of rocks for the refraction or reflection of the elastic wave energy. From suitable observations at

the surface it is possible to deduce the path followed by the elastic waves from their source to the point of observation. We deal, let us say, with somewhat hypothetical beams of sound as probes. And from a partial knowledge of the propagation velocities along complex refractive or reflective paths we calculate depths to the discontinuities responsible for these phenomena and attempt to map their configuration. To the layman the seismic method undoubtedly appears as a more direct and tangible method than any discussed thus far. Indeed it is direct in the sense that we have sent the energy of an explosive charge down to the depths desired and picked it up again at the surface. The energy observed at the detector and transcribed on a permanent record has actually touched or traversed the strata of interest. But the record includes such complexities introduced by intervening strata that one could hardly expect precise interpretations. As a matter of fact, in practical operations we are able to use only a part of the information that should be present on the record.

If we were dealing with a very simple system instead of the complex stratification comprising the subsurface, results could be expressed with absolute precision, and, in addition a great deal could be inferred regarding the nature of the strata encountered. Amplitudes, phase-shifts, shear as distinguished from dilational waves, all would have diagnostic significance. In practice, however, we measure only time intervals between initiation and reception of seismic events and from such time intervals and approximate velocity information our seismic maps are derived. It is impossible to say when, if ever, the other latent features may be used in adding detail to the interpretation. At the moment it appears that such details are stripped of all practical significance. Perhaps they are completely obliterated by the complexity of the path traversed. In fact, in some areas even the mere recognition of reflections is found impossible because of effects produced by surface or near-surface materials. Experience and improved instrumentation have gradually solved some of these problems and areas totally intractable in the recent past are now amenable to seismic work with reasonable results. Certainly this gradual improvement will continue, but it must be remembered that neither experience nor instrumentation can eliminate interfering phenomena introduced by the complexity of the geological section encountered. We have no control over the transmitting media and hence, the additional details which theoretically should be contained in seismic records and which might permit a more discerning analysis, may forever be obscured regardless of technical advances.

I sound this note of pessimism merely to point out the fallacy in expecting any magical over-night solution of these problems through instrumental improvements alone and that for some time to come the seismograph is likely to remain much the same as we now know it. Instrumental improvements will come but we should not lose sight of methods more obviously available whereby greater effectiveness of all types of geophysical work may be attained.

We have reviewed briefly the state of the geophysical art insofar as the orthodox magnetic, gravitational, electrical, and seismic methods are concerned. Thus far I have omitted mention of the geochemical methods, not because I am a confirmed disbeliever, but rather I am an agnostic, since it appears that several years of intensive research has provided no conclusive answer regarding their effectiveness. I believe we can say that there is a theoretically sound basis for such methods but only the future will tell to what extent it is amenable to practical application. At any rate, judging from past performance it is reasonable to assume that the status of geochemistry will not change suddenly to one of assured success, and apparently our direct oil-finder is still some distance around the corner.

I believe I have given a fair statement covering available geophysical principles. Throughout I have stressed the conclusion that we cannot rely upon any spectacular and revolutionizing instrumental improvements in any category to provide immediately the desired improvement in the oil-finding power of our instruments. But the story is not complete. These days we are prone to look to technological improvements as the sole solution to our problems. This is the attractive solution when it is within the realms of possibility but perhaps in the present case it will be more immediately profitable to look elsewhere.

It is my firm conviction, as has been expressed by others before me, that the effectiveness of geophysical exploration can be substantially increased by the mere application of more judicious handling of equipment, of the data obtained, and the geophysical talent available. Speaking in broad terms covering the industry as a whole, there is room for much improvement in the selection of proper instruments and technique for the job at hand. The refraction seismograph is still an effective tool when used in its proper place and perhaps in conjunction with the reflection method. The reflection seismograph is a powerful detailing tool when used properly and with reasonable discretion, but in connection with such work the density of control must be commensurate with the resolving power required. The data obtained from any method cannot be fully appraised by a cursory examination of

final maps as one might a contour map based on clear-cut surface or subsurface control points. The industry has developed an unfortunate attitude toward geophysical maps, particularly of seismograph data, because they are presented in the familiar and completely tangible form of subsurface contours. Having completed such a map it is assumed that the geophysicist's role ends there. Too often on the basis of such a map considered as the unique and positive solution of the seismic data, an area is condemned, or drilled and too frequently abandoned on the basis of inadequate tests. Moreover, the geophysicist himself is condemned along with his equipment, with the result that he becomes more and more conservative and unwilling to speculate beyond the most positive data visible on his records.

It is relatively easy to perceive the difficulty in piecing together a complete picture from electrical logs when the subsurface presents a complex problem, even though the measurements are made in drill holes and in direct contact with the strata. This problem is understood by all concerned. But the seismograph interpreter must piece together literally thousands of control points derived from elusive reflection events with possibilities of distortions and complex travel paths. And he is practically alone in his understanding of the problem. Under such conditions and in anticipation of the ever-present lash of criticism he is forced into a conservative attitude. And yet, the industry calls upon geophysics to find stratigraphic traps. The location of such traps by means of the seismograph is not an impossibility but it will be accomplished only by understanding and wholeheartedly accepting the risks that face the interpreter. When such an attitude is adopted, then and only then will an experienced interpreter dare present some of the obscure features he so frequently encounters in his data.

That the East Texas field could have been found only by wildcatting is a statement I have heard so often it seems to have become a truism. I am willing to agree that ten years ago and perhaps even now, a seismograph picture of the East Texas field would not have led to its discovery. However, it would not have been because of any failure of the reflection seismograph to show an interesting pinchout in the Woodbine horizon. But it would have required an imaginative and venturesome geologist working in close cooperation with a similar geophysicist to have exploited it as a prospective trap and to have picked within the wide pinchout zone the proper strip in which to hit production. Perhaps the East Texas seismograph picture is a textbook example, but doubtless there are others. In fact, any geophysicist can find among his data perhaps less clear-cut, yet reasonably good

examples of stratigraphic anomalies. Such data, however, are usually discussed and speculated upon for awhile among his co-workers, occasionally perhaps if circumstances permit with the geologist, and then they are filed away in his memory while he proceeds in the search for closed contours. For closed contours are the halos of certainty which alone have been generally acceptable as reasonable risks.

I am well aware of the practical considerations that relegate nebulous or speculative prospects to the discard. But the critics of the exploration department are demanding that we find not only structural features but stratigraphic and even lithologic traps, not to mention oil itself. It is folly to assume that such a goal can be attained without accepting greater risks than the industry in general is now willing or perhaps even able to assume. The more conservative attitude which seems to have made its entrance during the adolescent period of geophysics was suited to the times, or to any virgin oil province. But if we are being realistic in suggesting that the last drop of our domestic reserve must be found, then it is necessary to be equally realistic in action. If these reserves are to be found in stratigraphic or related traps then the industry must be prepared to accept and act upon seismograph data far less certain in character than has been acceptable in the past. Considering the nature of such traps it should be quite unnecessary to point out this fact. Nor should it be necessary to add that instrumental improvements alone will not result in the sudden emergence of stratigraphic and similarly obscure features as clear-cut prospects on a seismograph map.

It follows from such considerations that any successful attempt of the industry to delineate such illusive oil prospects by means of geophysics must be predicated on a change in the general attitude towards geophysics and its coordination with the policy-forming and exploitation departments. And I may as well be frank on this point.

Geophysics is spoken of as a tool for the geological department. Insofar as exploration is the normal function of the geological department, the statement is quite true. Indeed, it would be a high compliment attesting a simplicity and unimpeachable reliability to geophysics if such a connotation could be applied without qualification. But geophysics itself is not quite that certain of its answers. And until such time as geologists, and in particular executive geologists, are likewise geophysicists or have a thorough understanding of interpretation problems, the appellation should not be taken too literally. The seismograph, for example, is not a machine which by turn of a crank pours out maps to be read as one would the maps of a geodetic survey. On

the contrary, a large part of its effectiveness depends upon the human factor—the acuity and experience of the geophysicst. It is one thing to submit a report and a concise "yes or no" picture in the form of a map when dealing with some clear-cut structural feature. But it is quite another matter to present abstruse possibilities in similar form. In fact it is not done by any interpreter who has faced the music of the morning after. Nor will it be done until, more generally, the organizational structure of the exploration department is such as to give the geophysicist ready and regular access to the policy-making and action-formulating sanctums of the industry.

Geology did not achieve its maximum of usefulness in guiding land acquisitions and exploitation policy under a setup comparable to that generally assigned to geophysics. I need not review the history of geology's entrance into the petroleum industry to make my point clear. Geophysics may derive further comfort in a review of the history of the advent of production engineering and its even more modern technical phase into the industry.

No, I am not one who believes that geophysics is stagnating through lack of technological advances, although I freely admit and even emphasize that I cannot see new and revolutionizing tools on the horizon. But I do believe that as long as the industry is permitted to star gaze through the wrong end of the telescope, waiting for some magic out of the hat to bring the goal into sight, geophysics will continue to be condemned unjustifiably for its inability to find the illusive oil reserves which we are told are the hope of our domestic petroleum industry. It is the geophysicist's job to make this clear. It is also his job to point the way whereby those tools now at hand may be made more effective, using the same course whereby geology and production engineering succeeded.

Geophysics is, first of all, a scientific tool, but its practical application is as much an art as the practical application of geology, and the personal factor is and will remain its most potent complement. An imaginative and venturesome geophysicist is as necessary as the instruments he uses but in general the current administration of geophysics suppresses rather than encourages such traits. And in those organizations of which I speak, where geophysics is considered merely a tool rather than a part of the exploration machine, this trend will continue. And the industry will continue to cry for technological advances not available while it develops in the equally important human complement the very antithesis of desired progress.

THE GEOPHYSICAL HISTORY OF THE CAYUGA FIELD, ANDERSON COUNTY, TEXAS*

H. B. PEACOCK†

ABSTRACT

Original seismic maps based on the correlation method of reflection shooting are presented, together with a geological structure map. Cross sections show a comparison of the seismic and the well data. Results of a gravity-meter survey are also shown.

The East Texas Basin has experienced at least two rather distinct periods of geophysical activity as far as the seismic method is concerned. The first occurred in the spring and summer of 1927 when the greater part of this basin was prospected for salt domes and other structural features by the refraction seismograph. As to whether or not the Cayuga Area was explored at this time, no information is available, but it can be said that no structural evidence was obtained leading to the discovery of the field.

The second period of seismic activity started in late 1931 or early 1932 in the form of a general reconnaissance investigation by the reflection seismograph. Most previous reflection work in this area had been on the basis of Nacatoch, Pecan Gap or Austin Chalk reflections. In early 1932, the Lower Cretaceous became established as a reflecting horizon which gave considerable impetus to the work. The best reflection was believed to come from near the top of the Lower Cretaceous and was called the Georgetown reflection. It seems now that this is a misnomer, since it is becoming generally recognized at the present time that the Buda is present in this area and lies above the Georgetown. Throughout this discussion of seismic data, however, the name Georgetown will be used instead of Buda in speaking of the seismic horizon. In general, the so-called Georgetown reflection was found to be a more persistent and reliable marker than the shallower reflections and had the added advantage of showing more structural relief which made the seismic anomalies more pronounced and more easily identified.

It was during the course of this latter general reconnaissance survey that the Cayuga structure was discovered by Geophysical Service, Inc., working under contract to the Tide Water and Texas Seaboard

* Presented to the fourteenth annual meeting, Dallas, Texas, March 1944.

† Geophysical Service, Inc., Dallas, Texas.

Oil Companies. This structure lies in the extreme northwestern part of Anderson County and extends into Henderson County on the north and into Freestone County on the west. The surface conditions range from gently rolling woodland and farming land to low bottom land along the Trinity River. The Wilcox Formation outcrops over most of the upland area making the surface conditions somewhat variable. A few places are rather swampy in wet weather and deep sands occur along the east flank of the structure. Whether or not there are surface indications of structural uplift in this area may be disputed, but the structure was discovered during a purely reconnaissance seismic survey.

The first reflection survey line across the area was shot in September, 1932, and consisted of correlation points about a mile apart along the road leading from Tennessee Colony to Wildcat Ferry, which crossed the Trinity River near the northwest corner of the county. On this particular line, the Georgetown reflections were not outstanding and it was chiefly on the basis of the Pecan Gap reflections that reverse dips were sufficiently certain to justify additional checking in the area. Gradually, by intermittent periods of work, the survey was extended, working chiefly along roads or trails, until the structure was fairly well proved and outlined in a more or less general way on three reflecting horizons, the Pecan Gap, the Austin Chalk and the Georgetown. Figs. 1, 2, and 3 show a few key records taken in various parts of the area. The Pecan Gap reflection can usually be identified except where the initial energy on the record is so great as to mask the reflection. The Austin reflection is less persistent, energy apparently being reflected at times from the top of the formation and at other times from the base. In general, the basal reflections were found to be the more reliable. Over the area as a whole, the Georgetown reflection was the best marker. The character often changed somewhat from point to point but there was usually a sufficient number of records with good character to enable fairly accurate mapping.

Leasing was begun in the area on September 30, 1933, and little additional shooting was done until after the leasing was completed. Just before the first well was drilled, a more detailed east-west line, using a closer spacing of correlation points, was shot through the proposed location as a final check on the structure. This line confirmed the previous work and drilling was commenced on February 2, 1934, on the Tide Water and Texas Seaboard #1 Edens Well in the Samuel Snider Survey. This proved to be the discovery well for the field and was completed on March 2, 1934, in the Woodbine sand

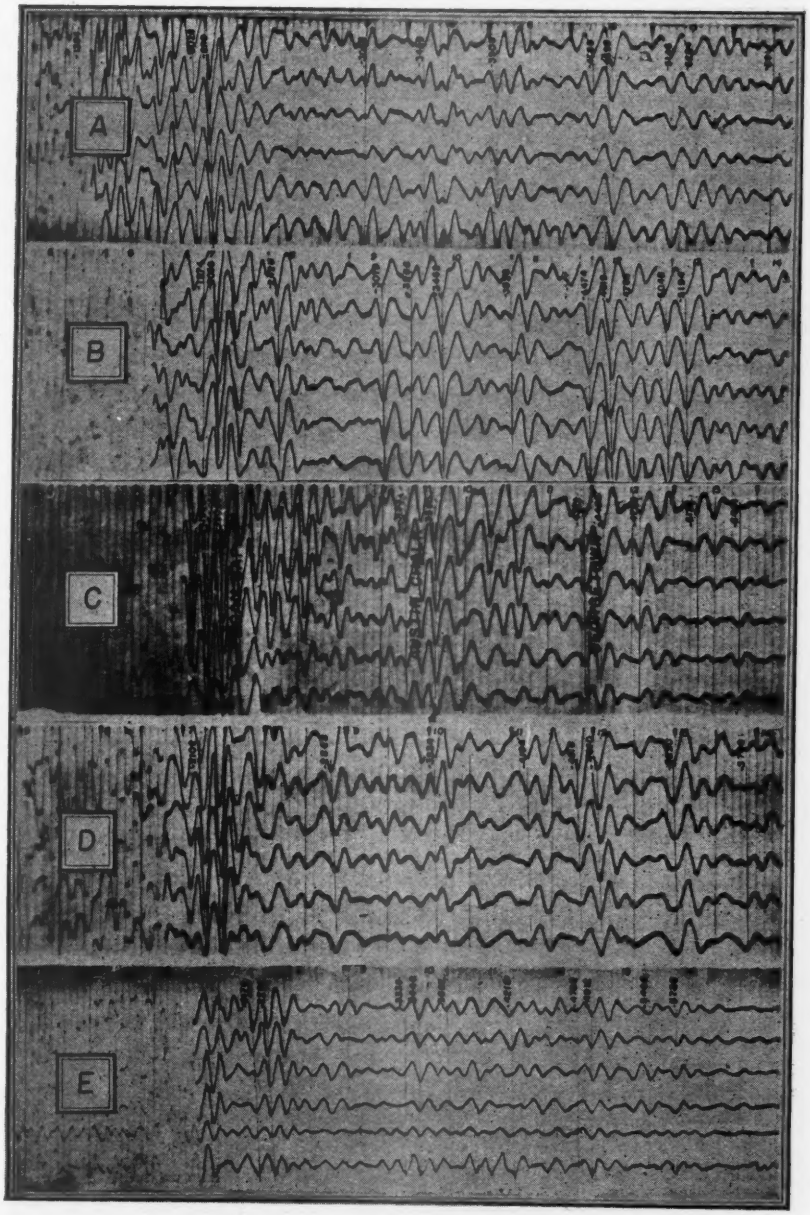


FIG. 1. Cayuga area seismograms aligned on "Georgetown" reflection. Data plotted on X–X' section. (See Fig. 6 for locations.)

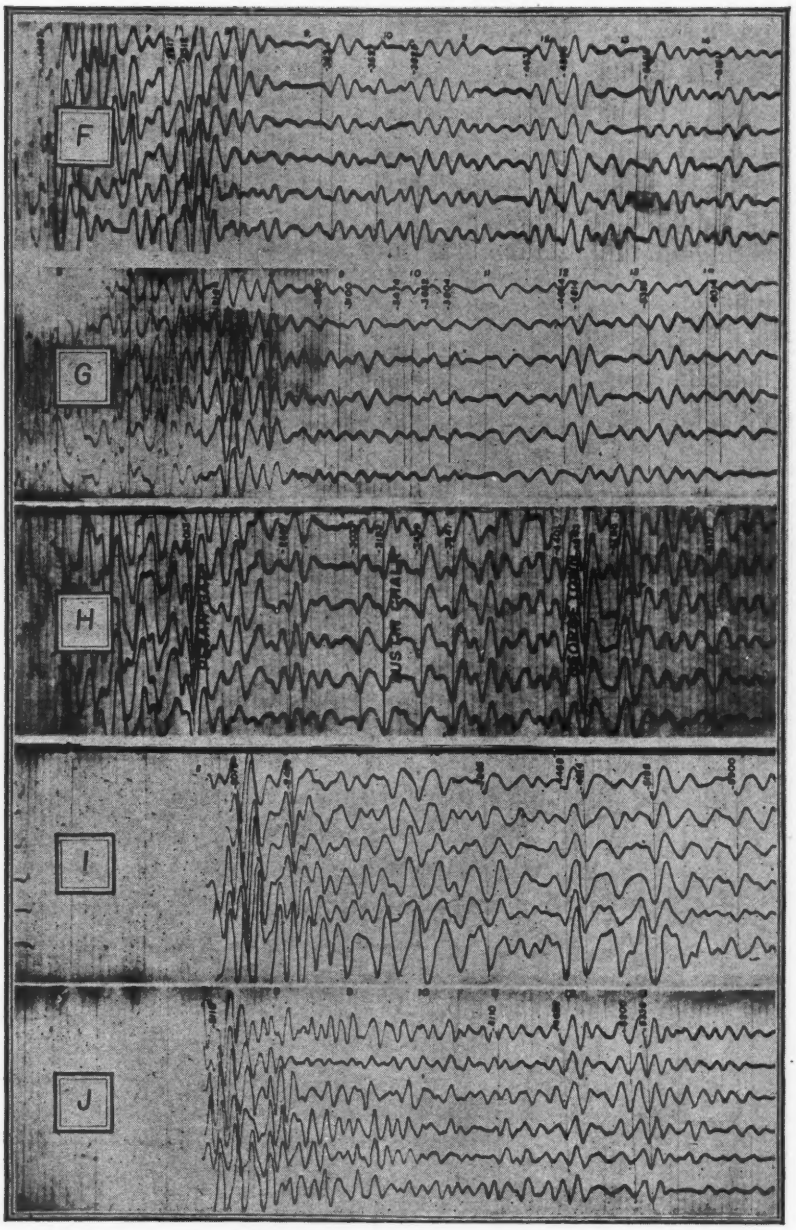


FIG. 2. Cayuga area seismograms aligned on "Georgetown" reflection. Data plotted on *Y–Y'* section. (See Fig. 6 for locations.)

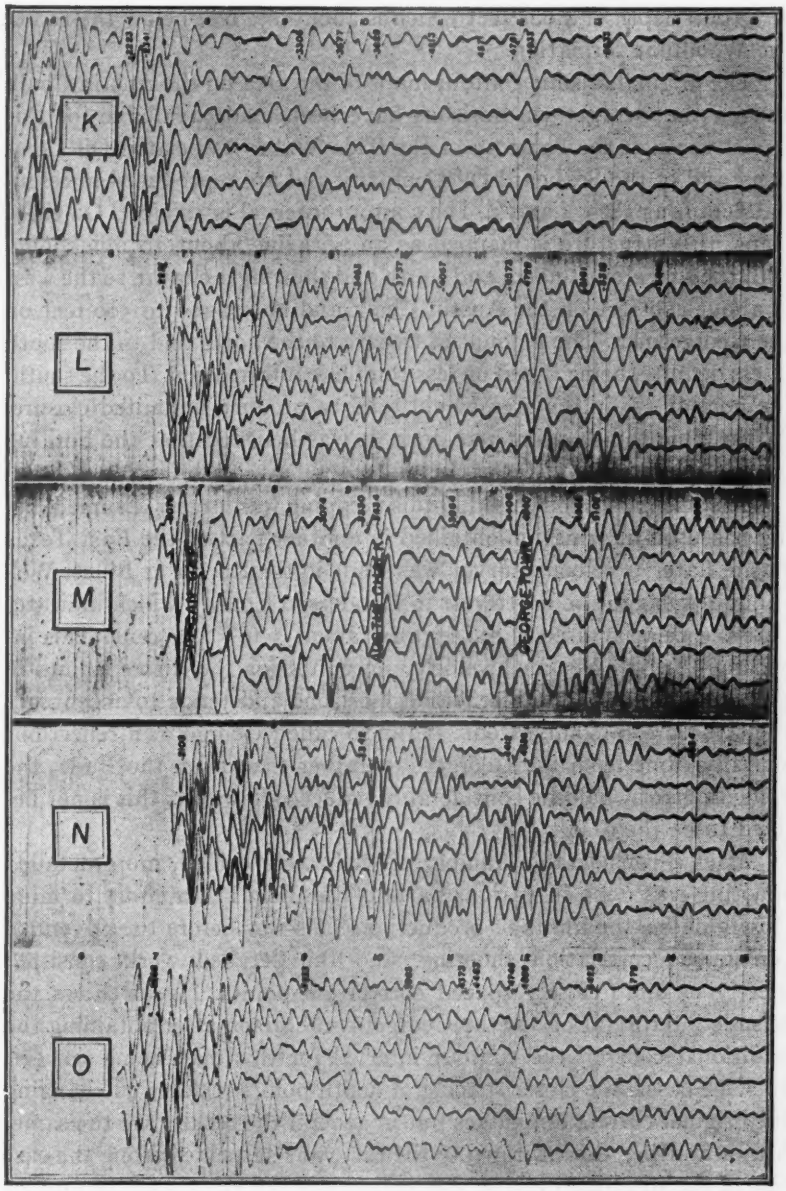


FIG. 3. Cayuga area seismograms aligned on "Georgetown" reflection. Data plotted on Z–Z' section. (See Fig. 6 for locations.)

at a total depth of 4,088 feet which is about 250 feet below the top of the Woodbine formation.

The original seismic contour maps of the area on the Austin Chalk and on the Georgetown horizons have been made available for this report through the courtesy of the Tide Water Associated Oil Company and of the Seaboard Oil Company and are reproduced in essential details as Figs. 4 and 5. The contour interval is 100 feet. On these maps, this structure is mapped as an anticline about 10 miles long, with the axis almost north and south and showing a closure to the west of about 200 feet on the Austin Chalk and about 400 to 500 feet on the Georgetown. The amount of closure to the north and to the south is less definite, being based on less complete information. To the south, the normal dip in the area would tend to produce unlimited closure. At the time the shooting was done, it was believed that the limiting closure was probably to the north.

The seismic velocity used in this mapping was largely assumed, being based on information obtained in another part of the East Texas Basin. Later, a velocity survey was made in the Roeser #1 Billett Well about 4 miles to the northwest in Henderson County which indicates that the velocity used is too high by about 3 to 5 per cent. This inaccuracy in the assumed velocity accounts for the discrepancies in the datum values to the reflecting horizons and tends to accentuate the structure to some extent. If the so-called Georgetown reflections actually came from the Georgetown rather than from the Buda, the velocity error would be considerably reduced; however, this is not believed to be the case.

After a considerable number of wells were drilled, more detailed shooting was done in various parts of the field in an effort to more closely define the limits of production. This was before the advent of continuous correlation shooting, and the detailed work consisted merely of more closely spaced correlation points. Fig. 6 shows the seismic interpretation for the Georgetown horizon after obtaining the additional control, the contour interval for this map being 50 feet. In some cases, the closer spacing of depth points resulted in changing the original correlation values but in general the results are the same. Major faulting, downthrown to the east, was suspected along the east side of the structure even on the preliminary mapping, and the greater number of irregularities shown on the later map were believed to be due to faulting. However, at no time was the complicated pattern of faulting which is indicated by drilling ever considered as a possibility.

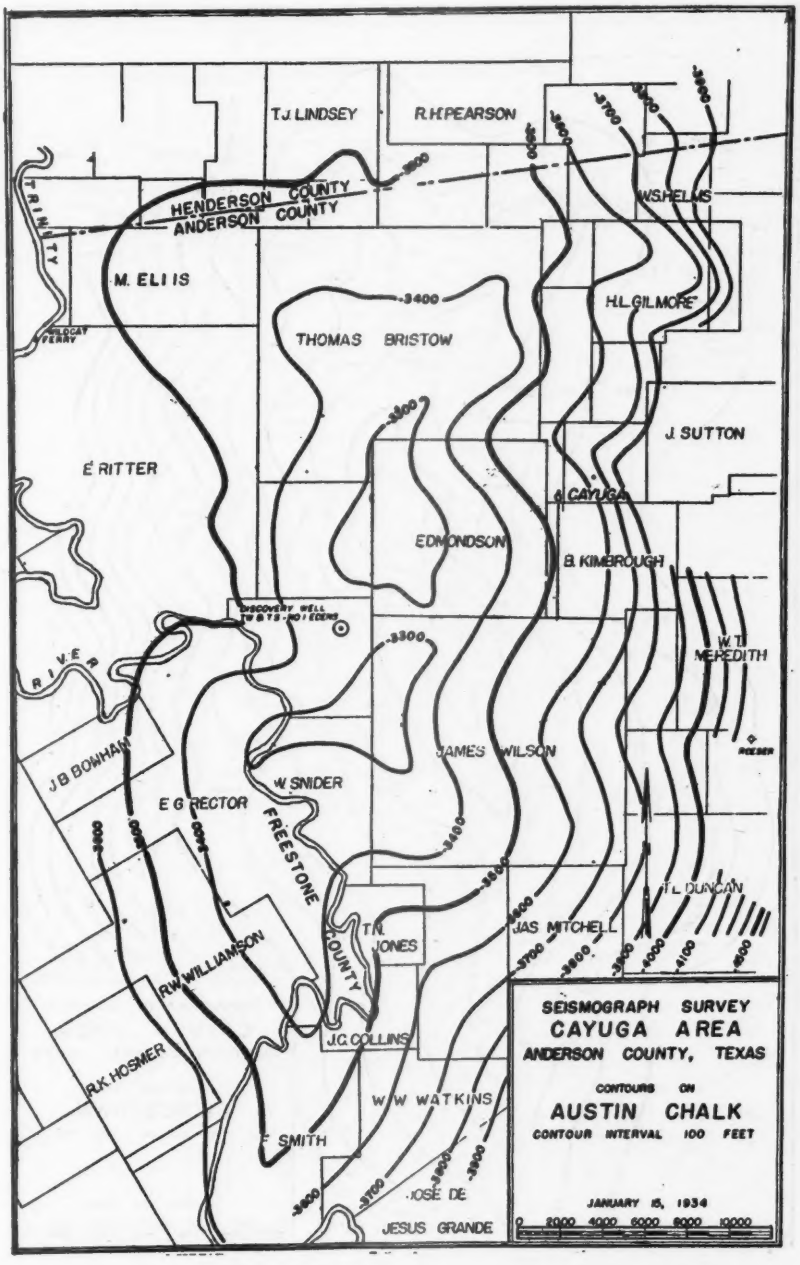


FIG. 4. Early (January 1934) seismic map of the Cayuga Area, contoured on the "Austin Chalk." Contour interval is 100 feet.

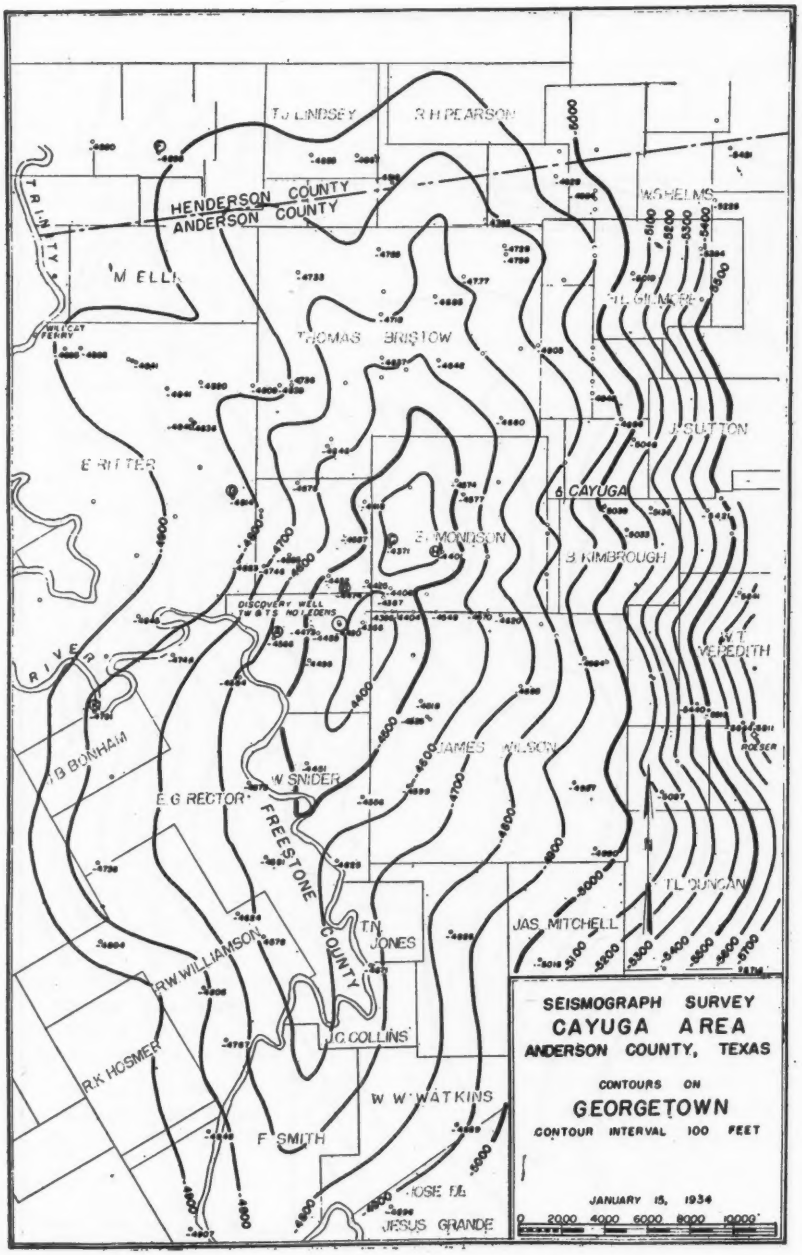


FIG. 5. Early (January 1934) seismic map of the Cayuga Area, contoured on the "Georgetown." Contour interval is 100 feet.

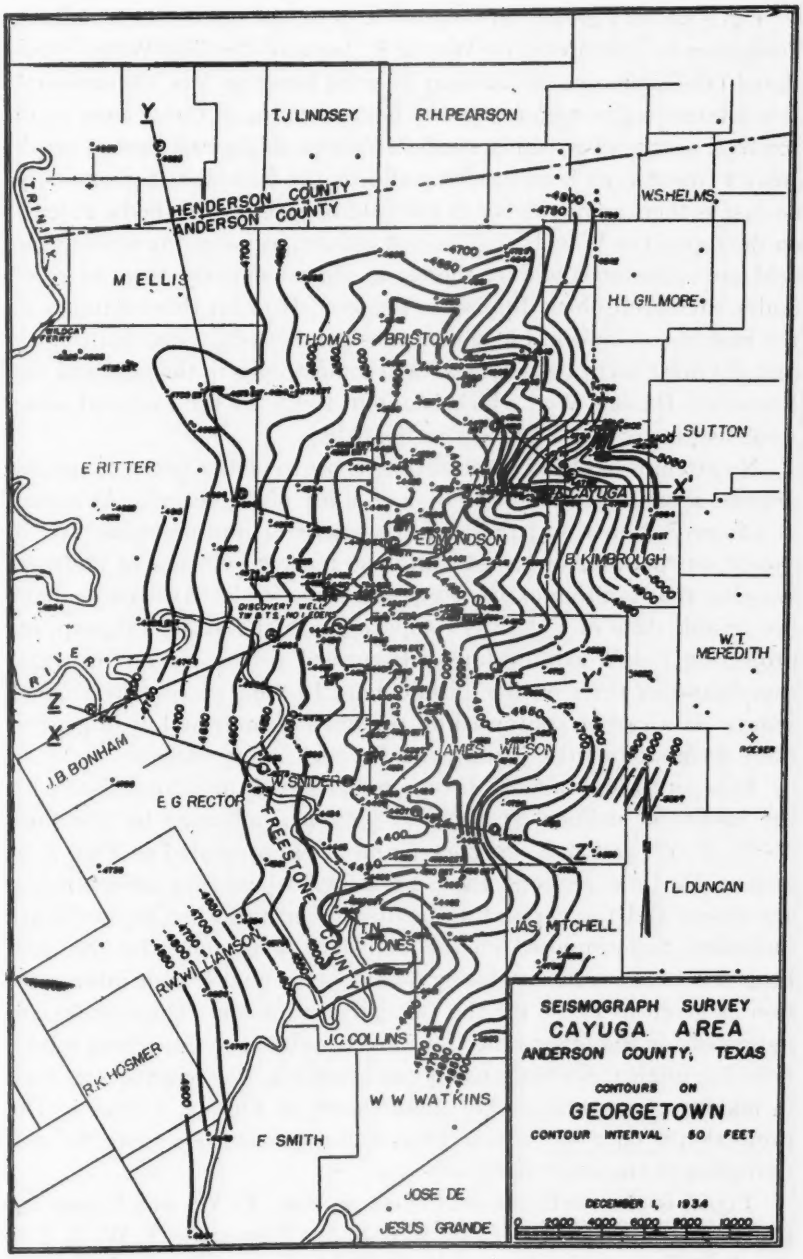


FIG. 6. Final (December 1934) seismic map of the "Georgetown" reflection in the Cayuga area, showing the location of the cross sections *X–X′*, *Y–Y′*, and *Z–Z′*, and the points at which the seismograms of Figs. 1–3 were obtained. Contour interval is 50 feet.

Fig. 7 shows a geological contour map on the top of the Woodbine Formation as interpreted by Wayne V. Jones of the Tide Water Associated Oil Company, the contour interval being 50 feet. Of considerable interest is the large number of faults varying in throw from 25 to 200 feet, nearly all of which are downthrown to the east; but of much greater interest, at least academically, is the fact that in practically no case is there any evidence in the field of east-dipping beds, at least on the top of the Woodbine. The east closure, as far as the wells in the field are concerned, is due, therefore, almost entirely to a series of faults, each fault block dipping to the west. How far this continues to the east is not known, but either considerable additional faulting or east dip must occur between the easternmost wells in the field and the Roeser #1 Daniels Well which is about a mile to the east and some 1,000 feet lower than the wells in the field.

No attempt has been made in this report to justify or to change the original seismic interpretation by a re-study of the records. As occurs in all correlation work, there are questions of interpretation and it should not be difficult to read into the records evidence of faulting, knowing that faulting exists. However, some study has been made of the seismic data of Fig. 6 as compared with the geological map, by projecting the Woodbine faults downward to the Georgetown and superimposing them on the seismic map. In some places, the original seismic data can be contoured on the basis of faulting but in general there seems to be little justification for such interpretation.

In order to show a more direct comparison of the seismic data with the results of drilling, three cross sections, indicated by the lines X–X', Y–Y', and Z–Z' on Figs. 6 and 7, are presented as Figs. 8, 9, and 10. On these sections, the electric logs, where they are available, are shown and the correlating points on certain other key wells are indicated. Superimposed on the well data, and shown by the light broken lines between correlating points, is the final seismic interpretation as given in Fig. 6 for the Georgetown horizon. The correlations indicated for the other reflections are based largely on recent study, since the original correlations are not available. The seismograms used in making these sections are those shown in Figs. 1, 2, and 3. The projection of data for these sections was approximately along the contour lines of the maps involved.

Fig. 8 is the northeast-southwest section, X–X', which runs approximately through the T. W. A. & S. #15 Edens, the T. W. A. & S. #21-A Wills and the Barnsdall #2 Tubbs wells, all of which were drilled below the Georgetown. Faulting is quite evident on this section

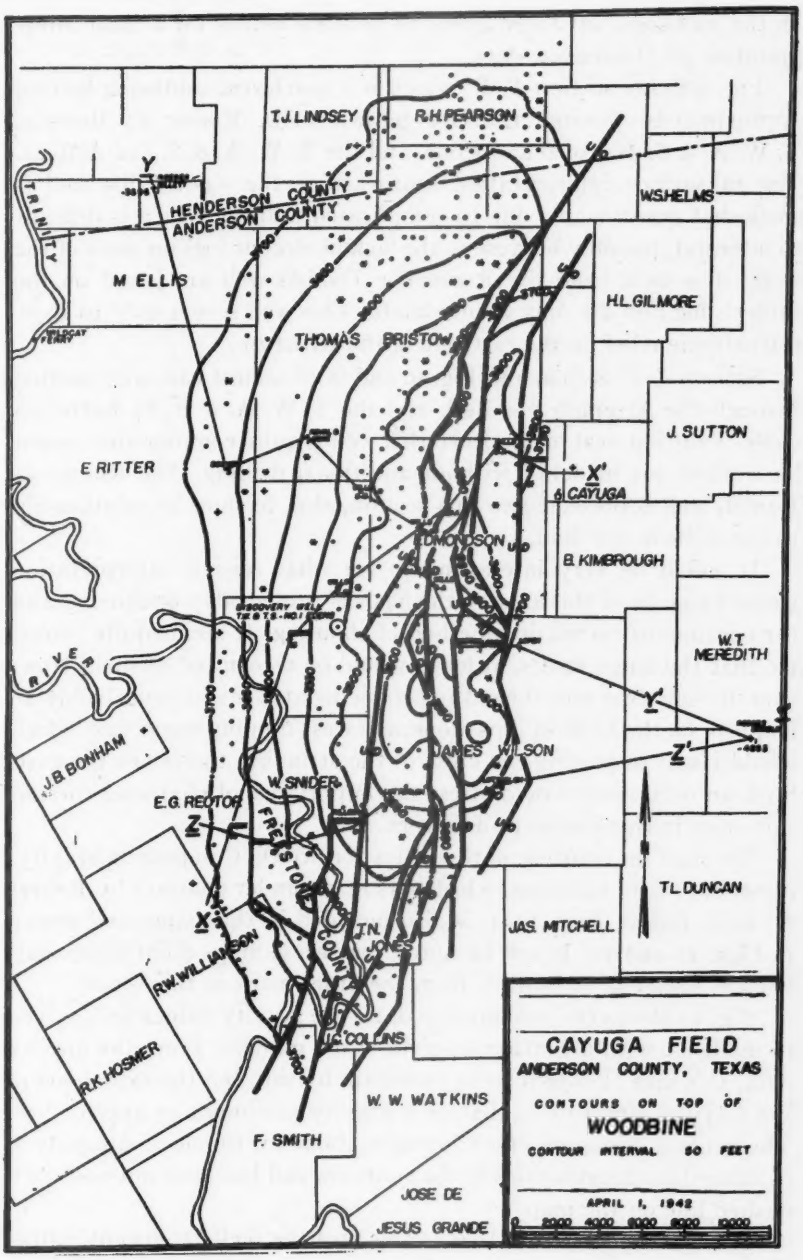


FIG. 7. Geological map of the Cayuga Field as of April 1942, contoured on the top of the Woodbine formation, showing the location of the wells used in making the cross sections. Contour interval is 50 feet.

on the well logs, but there seems to be little reason for a fault interpretation on the seismic data.

Fig. 9 shows section $Y–Y'$ which is a northwest-southeast section approximately through the Georgetown wells, Roeser #3 Bowyer, T. W. A. & S. #1 Royal and Cone, and the T. W. A. & S. #21-A Wills. The subsurface interpretation southeast of the #3-A Wills well is somewhat questionable due to complicated faulting which is difficult to interpret, possibly because of the lack of electric logs on some of the wells. The data from the Roeser #1 Daniels well are based on the driller's log and are only approximate. This well serves only to show the extreme relief on the east side of the structure.

Section $Z–Z'$ is shown in Fig. 10 and is an almost east-west section through the Amerada #14 Berk and the T. W. A. & S. #7 Lutterloh wells. Faulting east of the Lutterloh well is quite complex and cannot be worked out in detail without additional drilling. The Roeser #1 Daniels well is projected to this section, also, to show its relationship to the wells in the field.

It would be very interesting to see what seismic interpretation would be made of this area on the basis of present-day equipment and the continuous correlation method of shooting. It seems quite probable that the larger faults, at least, would be recognized as such. However, if they were not, the entire producing area might conceivably be mapped, on the basis of dips alone, as a west-dipping monocline, which would result in placing the crest of the structure too far to the east. Such an occurrence would stress the importance of character correlation even in continuous profile work.

Through the courtesy of the Cities Service Oil Company, a gravity-meter survey of this area, which was made under contract by Robert H. Ray, Inc. in July, 1941, is also included in this paper and shown in Figs. 11 and 12. It will be noted that these maps differ somewhat, both in scale and in outline, from the other maps in this report.

Fig. 11 shows the true gravity data, the gravity values being given in milligals, with a contour interval of 0.2 milligal. From the gravity data, this area is judged to be underlain by salt and the expression of the Cayuga structure is that of a gravity minimum or gravity low. The general minimum effect brought about by this local anomaly is evidenced by irregularities in the contours and has been outlined by a dashed line on the map.

It may be pointed out that in this area the regional gravity values increase to the northwest and that the true gravity values shown in

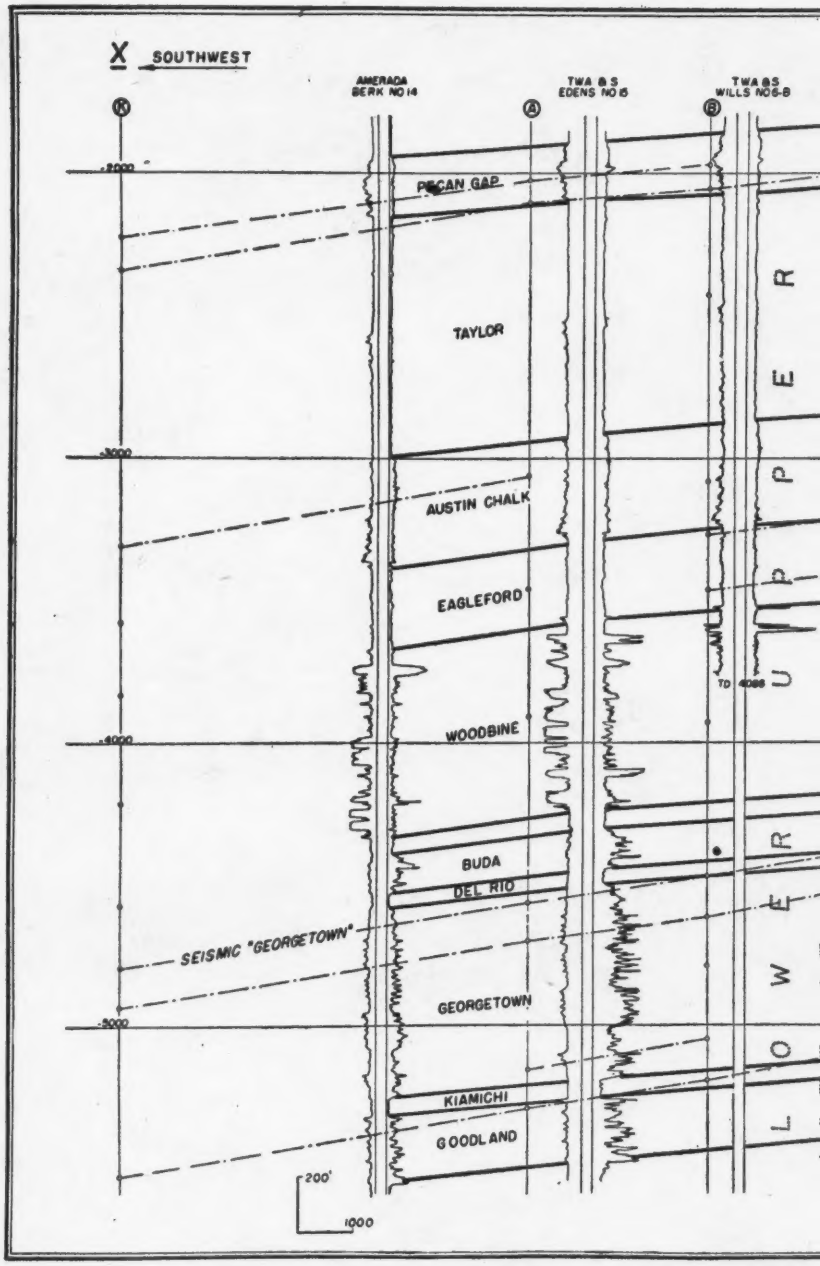
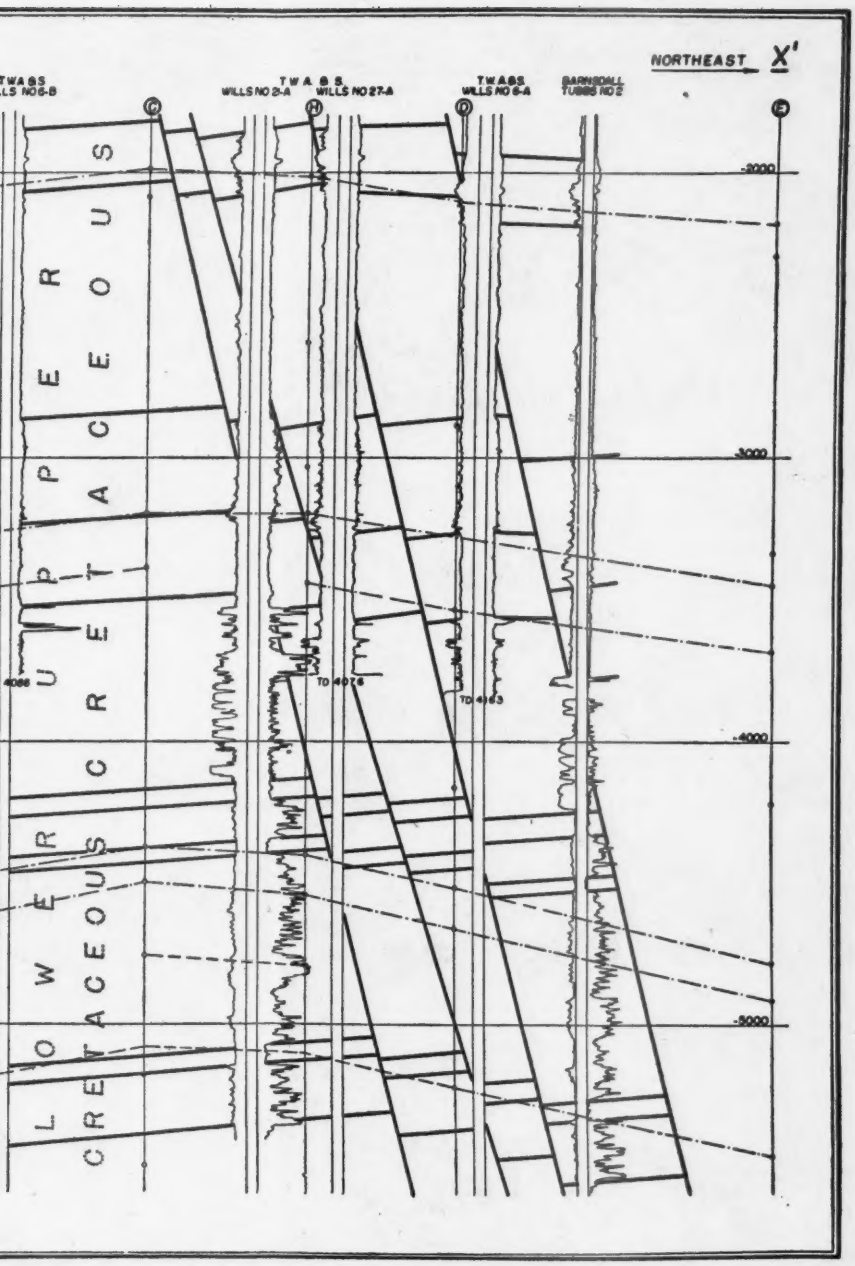


FIG. 8. *X–X′* cross section of the Cayuga field, showing the electric logs, ge
interpretation of the subsurface data, d



c logs, geologic interpretation, and seismic horizons. Solid lines are the geologic
e data, dash-dot lines the seismic horizons.

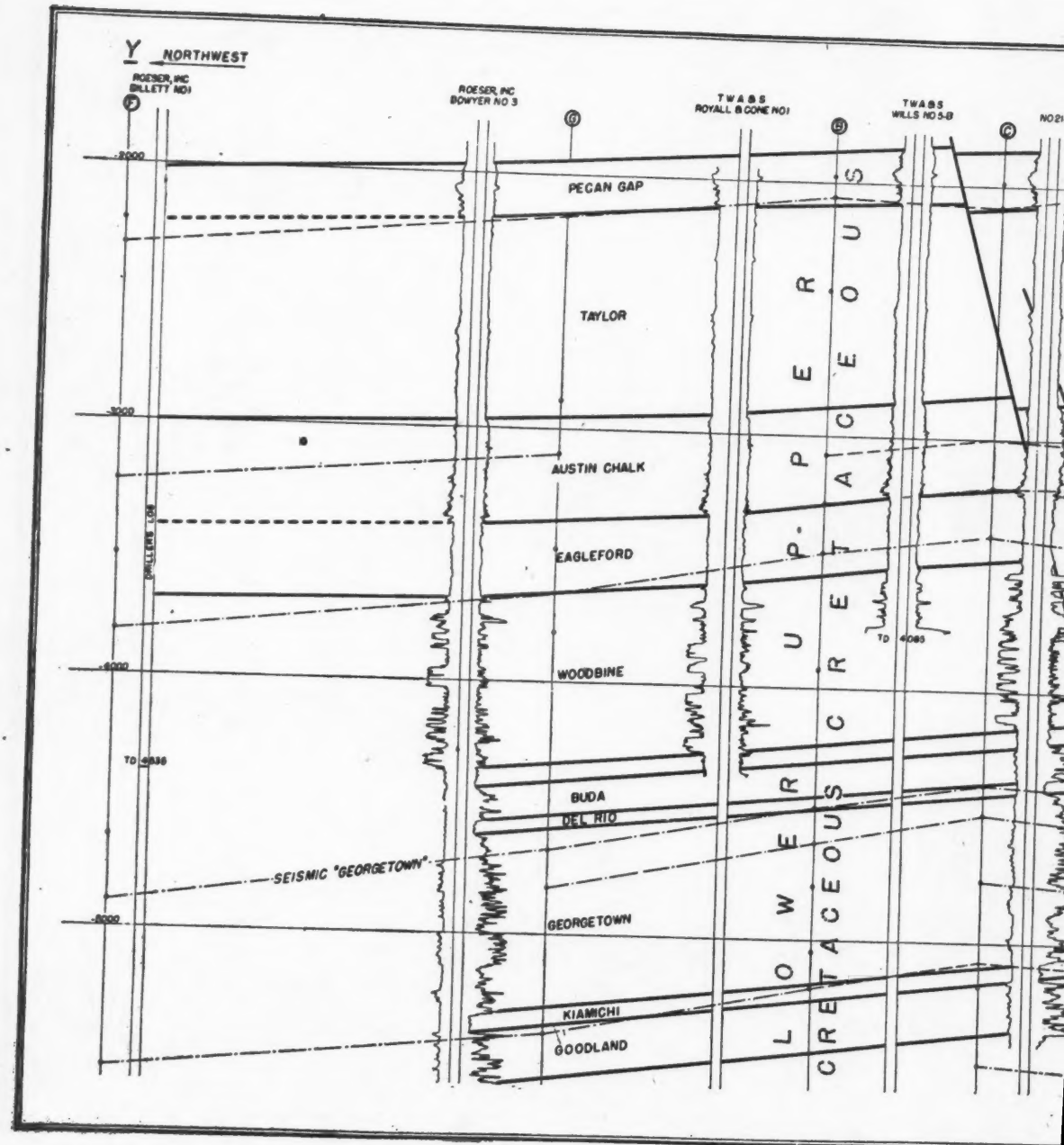
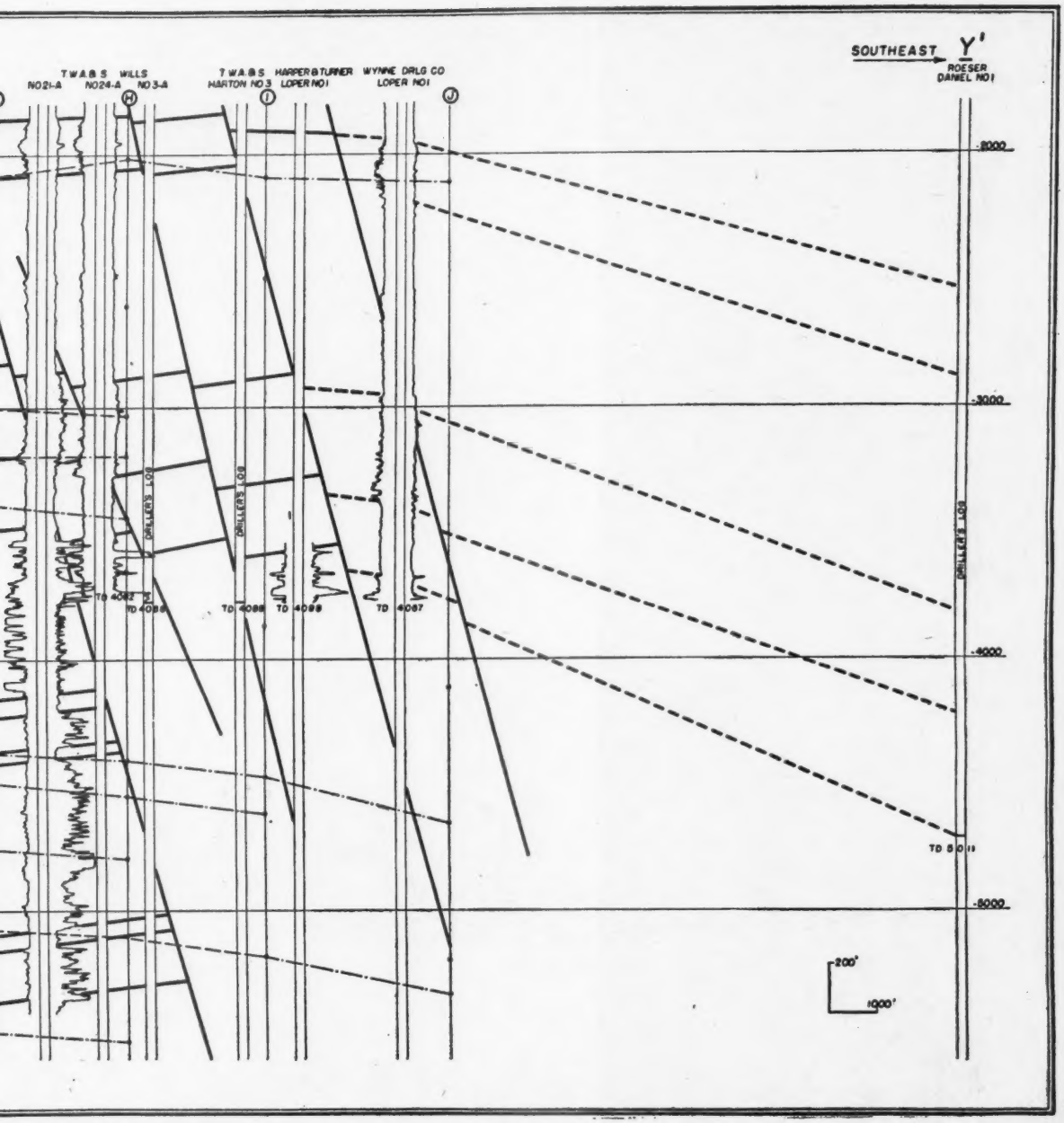


FIG. 9. *Y–Y′* cross section of the Cayuga field, showing the electric logs, geologic interpretation, and seismic horiz



ismic horizons. Solid lines are the geologic interpretation of the subsurface data, dash-dot lines the seismic horizons.

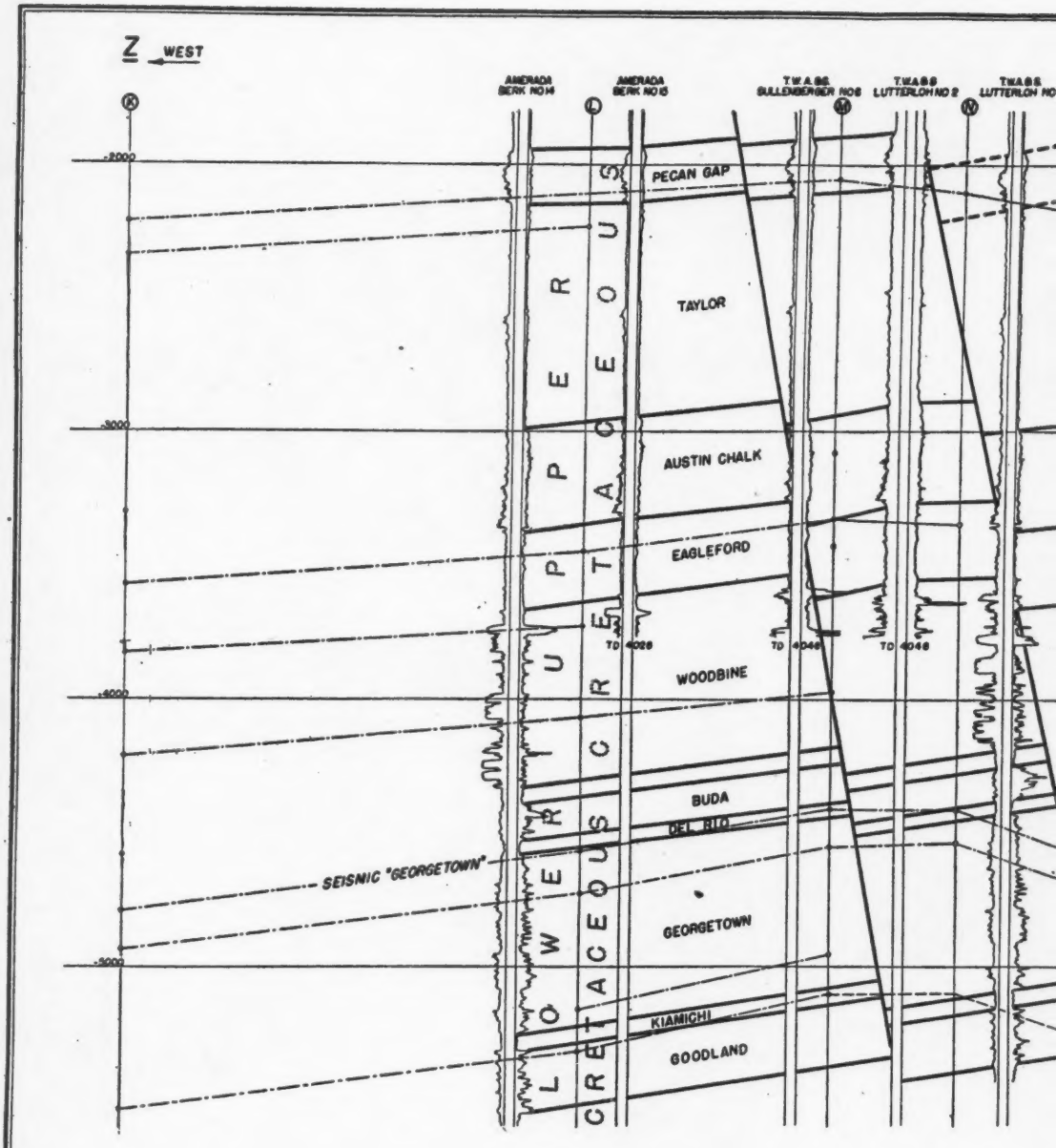
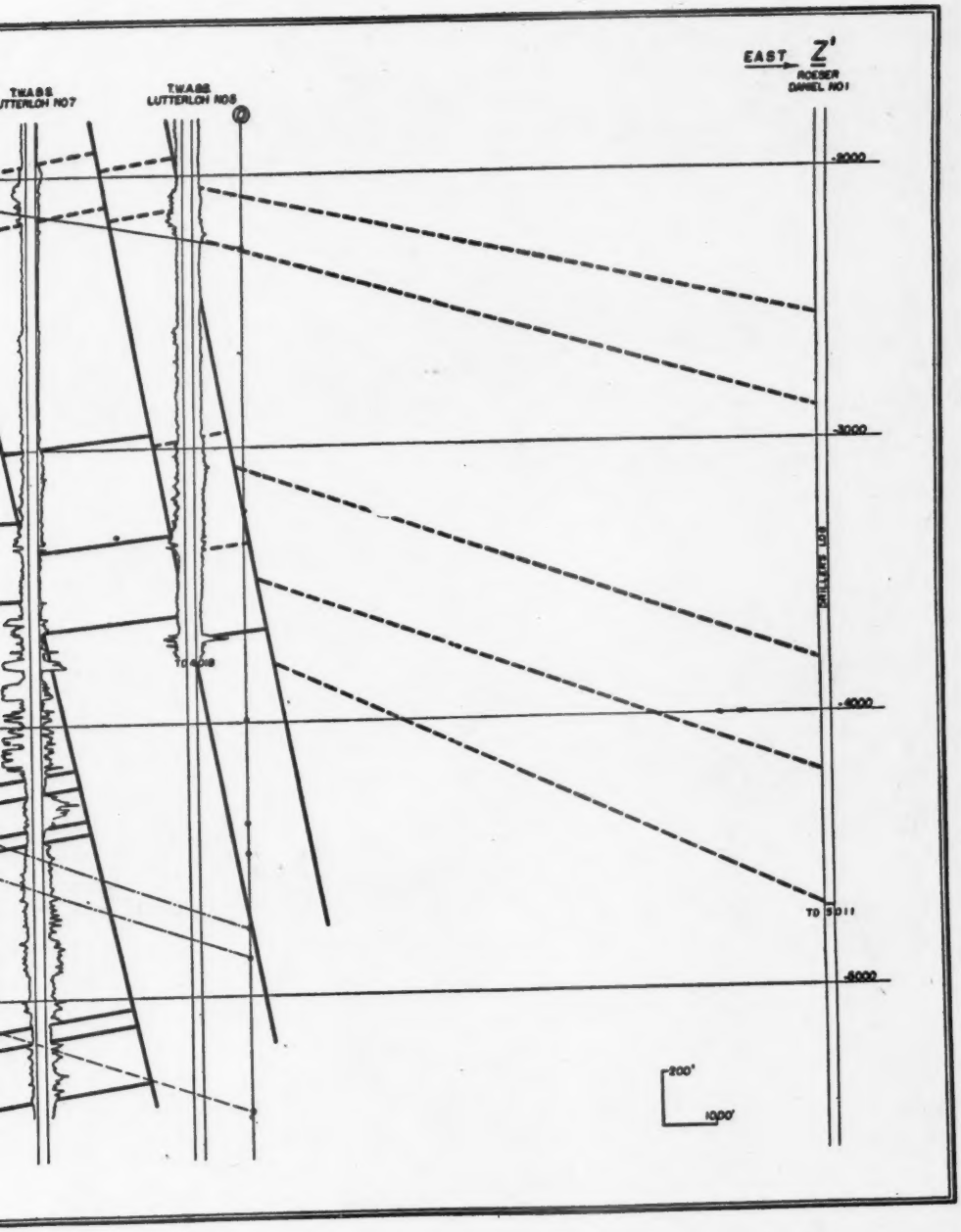


FIG. 10. *Z–Z′* cross section of the Ca



n of the Cayuga Field.

Fig. 11 represent the sum of the local effect and the regional effect. In order to show more clearly the effect of the local anomaly, a corrected or residual map is shown in Fig. 12 which represents the gravity picture after subtracting the regional effects. On this map the gravity minimum is more clearly defined. The maximum gravity area to the east and southeast marks the structurally low or normal zone between the Cayuga structure and the Bethel Salt Dome which lies a short distance to the southeast.

The writer wishes to thank the Tide Water Associated Oil Company, the Seaboard Oil Company, the Cities Service Oil Company and Robert H. Ray, Inc., for their cooperation in preparing this report and for making available for publication the data contained herein.

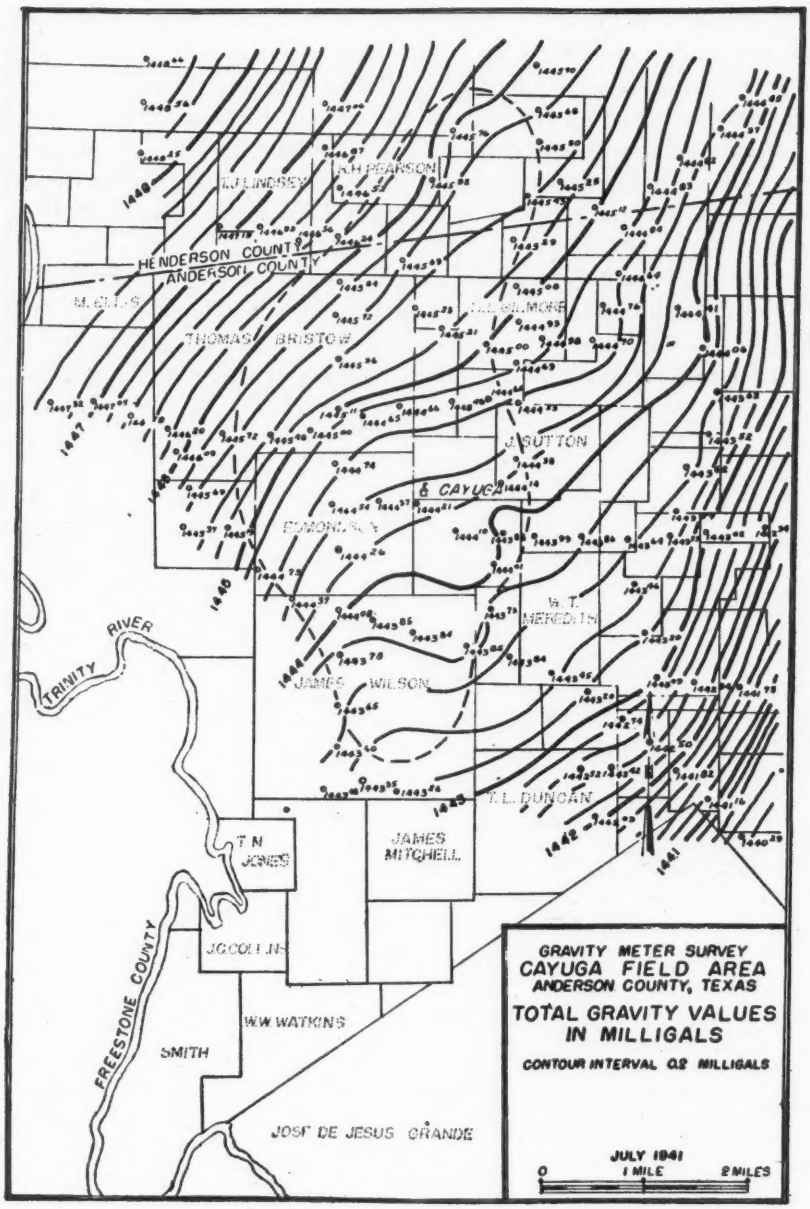


FIG. 11. Observed gravity values over the Cayuga Field area. Contour interval is 0.2 milligals.

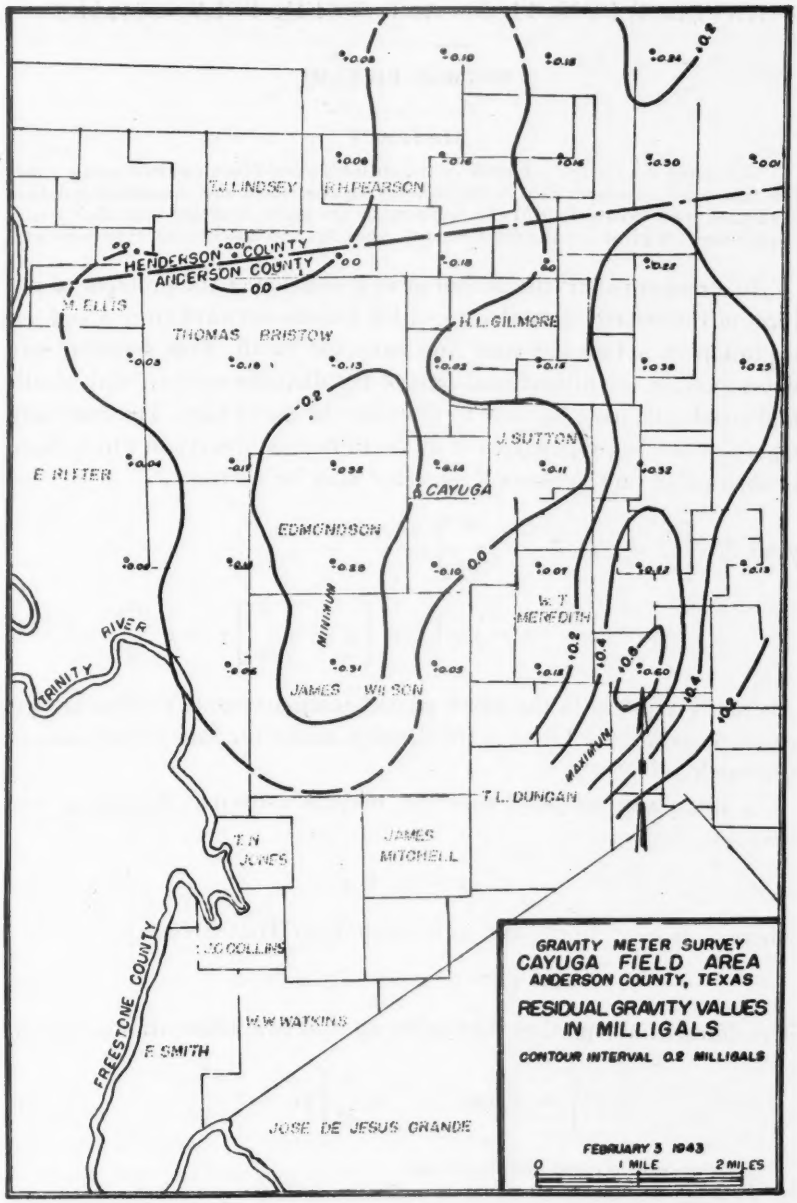


FIG. 12. Residual gravity values, after removal of the regional, over the Cayuga Field area. Contour interval is 0.2 milligals.

WAVELET FUNCTIONS AND THEIR POLYNOMIALS*

NORMAN RICKER†

ABSTRACT

This paper is a further extension of the author's *wavelet theory of seismogram structure*. The *wavelet functions* used in the previous paper are extended, a modified notation is adopted, and twenty four of the polynomials are given, together with their roots. Expressions are given for the displacement, velocity, and acceleration type wavelets.

In a recent paper[1] the author gave a solution of the problem of the form of the seismic disturbance which travels outward from a sudden explosion in a homogeneous and isotropic earth. This solution was developed for the dilatational part of the disturbance but, with modified constants, may be used to describe the shear part. The complete equation for the propagation of waves in an elastic earth in which there is absorption due to *internal viscosity*[2] may be written

$$\text{grad div}\left[(\lambda + 2\mu) + \frac{4}{3}\eta\frac{\partial}{\partial t}\right]\chi - \text{curl curl}\left[\mu + \eta\frac{\partial}{\partial t}\right]\chi = \rho\frac{\partial^2\chi}{\partial t^2} \tag{1}$$

wherein χ represents the earth particle displacement, λ and μ are the elastic constants of Lamé, ρ the density, and η the *internal viscosity* of the earth.

χ, being a vector point function, may be written as the sum of two vectors

$$\chi = \chi_1 + \chi_2 \tag{2}$$

where χ_1 is irrotational and χ_2 is solenoidal. That is to say

$$\text{curl}\,\chi_1 = 0 \quad \text{and} \quad \text{div}\,\chi_2 = 0. \tag{3}$$

The differential equation thus splits up into two differential equations

$$\nabla^2\left[(\lambda + 2\mu) + \frac{4}{3}\eta\frac{\partial}{\partial t}\right]\chi_1 = \rho\frac{\partial^2\chi_1}{\partial t^2} \tag{4}$$

* Manuscript received March 1, 1944.

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[1] Norman Ricker, *Further developments in the wavelet theory of seismogram structure.* Bull. Seismol. Soc. Amer., Vol. 33 (1943), pp. 197–228.

[2] *Loc. cit.*, p. 197.

and

$$\nabla^2\left[\mu + \eta\frac{\partial}{\partial t}\right]\chi_2 = \rho\frac{\partial^2\chi_2}{\partial t^2}. \tag{5}$$

Calling

$$c = [(\lambda + 2\mu)/\rho]^{1/2} \tag{6}$$

and

$$\bar{c} = (\mu/\rho)^{1/2} \tag{7}$$

These equations become

$$\nabla^2\left[\chi_1 + \frac{4\eta}{3\rho c^2}\frac{\partial\chi_1}{\partial t}\right] = \frac{1}{c^2}\frac{\partial^2\chi_1}{\partial t^2} \tag{8}$$

and

$$\nabla^2\left[\chi_2 + \frac{\eta}{\rho\bar{c}^2}\frac{\partial\chi_2}{\partial t}\right] = \frac{1}{\bar{c}^2}\frac{\partial^2\chi_2}{\partial t^2}. \tag{9}$$

Calling

$$\omega_0 = 3\rho c^2/4\eta \tag{10}$$

and

$$\bar{\omega}_0 = \rho\bar{c}^2/\eta. \tag{11}$$

The equations are now

$$\nabla^2\left[\chi_1 + \frac{1}{\omega_0}\frac{\partial\chi_1}{\partial t}\right] = \frac{1}{c^2}\frac{\partial^2\chi_1}{\partial t^2} \tag{12}$$

and

$$\nabla^2\left[\chi_2 + \frac{1}{\bar{\omega}_0}\frac{\partial\chi_2}{\partial t}\right] = \frac{1}{\bar{c}^2}\frac{\partial^2\chi_2}{\partial t^2}. \tag{13}$$

These are the equations of wave propagation of the dilatational and shear disturbances respectively. The quantities ω_0 and $\bar{\omega}_0$ are constants of the medium as defined by Eqs. 10 and 11 above. The transition frequencies of the medium are given by

$$f_0 = \frac{\omega_0}{2\pi} \quad \text{and} \quad \bar{f}_0 = \frac{\bar{\omega}_0}{2\pi}. \tag{14}$$

These transition frequencies are the frequencies above which dispersion becomes important for continuous sinusoidal waves. We have the relation

$$\frac{\bar{\omega}_0}{\omega_0} = \frac{4}{3}\left(\frac{\bar{c}}{c}\right)^2. \tag{15}$$

We shall carry along for the remainder of the paper using the constants for the dilatational part of the disturbance with the understanding that the shear wave counterpart may be obtained by replacing ω_0 by $\bar{\omega}_0$ and c by $\bar{c}$.

For plane waves moving along the x axis, Eq. 12 becomes

$$\frac{\partial^2}{\partial x^2}\left(\Phi + \frac{1}{\omega_0}\frac{\partial \Phi}{\partial t}\right) = \frac{1}{c^2}\frac{\partial^2 \Phi}{\partial t^2}. \tag{16}$$

Φ is a generating function from which χ is obtained by

$$\chi = \frac{\partial \Phi}{\partial t}$$

Introducing dimensionless quantities X and T which we shall call *numerical distance* and *numerical time* respectively, defined as

$$X \equiv \frac{\omega_0 x}{c} \quad \text{and} \quad T \equiv \omega_0 t, \tag{17}$$

Eq. 16 becomes

$$\frac{\partial^2}{\partial X^2}\left(\Phi + \frac{\partial \Phi}{\partial T}\right) = \frac{\partial^2 \Phi}{\partial T^2}, \tag{18}$$

A solution of this equation may be written

$$\Phi = \sum_{n=0}^{\infty}\left(\frac{2}{X}\right)^{(n+1)/2} \Psi_n(u), \tag{19}$$

wherein

$$u \equiv 2^{1/2} \cdot X^{-1/2}(T - X), \tag{20}$$

and $\Psi_n(u)$ is the *wavelet function* of order n. From this solution the three important forms of seismic disturbance may be obtained. Denoting by a dot a derivative with respect to T, and by a prime a derivative with respect to the argument of a function, we have the following:

The displacement function.

$$\dot{\Phi} = \sum_{n=0}^{\infty}\left(\frac{2}{X}\right)^{(n+2)/2} \Psi_n'(u). \tag{21}$$

The velocity function.

$$\ddot{\Phi} = \sum_{n=0}^{\infty} \left(\frac{2}{X}\right)^{(n+3)/2} \Psi_n''(u). \tag{22}$$

The acceleration function.

$$\dddot{\Phi} = \sum_{n=0}^{\infty} \left(\frac{2}{X}\right)^{(n+4)/2} \Psi_n'''(u). \tag{23}$$

The wavelet function $\Psi_n(u)$ may be written

$$\Psi_n(u) \equiv S_n{}^0(u) \cdot \Psi_0(u) \tag{24}$$

wherein

$$\Psi_0(u) \equiv \frac{\sqrt{\pi}}{2} \cdot e^{-u^2/4} \tag{25}$$

and $S_n{}^0(u)$ is a polynomial of degree $3n$. Similarly, the m-th derivative of $\Psi_n(u)$ may be written

$$\frac{d^m}{du^m} \Psi_n(u) = S_n{}^m(u) \cdot \Psi_0(u) \tag{26}$$

wherein $S_n{}^m(u)$ is a polynomial of degree $3n+m$. These polynomials are given below for $n=0$ to 5, and for $m=0$ to 3 inclusive.

$$\left.\begin{aligned}
S_0{}^0 &= \left(\frac{3}{4}\right)^0 \cdot \frac{1}{2^0 \cdot 0!} = 1 \\
S_1{}^0 &= \left(\frac{3}{4}\right)^1 \cdot \frac{1}{2^3 \cdot 1!} (u^3 - 6u) \\
S_2{}^0 &= \left(\frac{3}{4}\right)^2 \cdot \frac{1}{2^6 \cdot 2!} \left(u^6 - \frac{190}{9} u^4 + \frac{220}{3} u^2 - \frac{40}{3}\right) \\
S_3{}^0 &= \left(\frac{3}{4}\right)^3 \cdot \frac{1}{2^9 \cdot 3!} \left(u^9 - \frac{136}{3} u^7 + \frac{4,648.}{9} u^5 - \frac{12,320.}{9} u^3 + \frac{560}{3} u\right) \\
S_4{}^0 &= \left(\frac{3}{4}\right)^4 \cdot \frac{1}{2^{12} \cdot 4!} \left(u^{12} - \frac{236}{3} u^{10} + \frac{50,620.}{27} u^8 - \frac{411,488.}{27} u^6 \right. \\
&\qquad \left. + \frac{298,480.}{9} u^4 - \frac{24,640.}{9} u^2 + \frac{2,240.}{9}\right) \\
S_5{}^0 &= \left(\frac{3}{4}\right)^5 \cdot \frac{1}{2^{15} \cdot 5!} \left(u^{15} - \frac{1,090.}{9} u^{13} + \frac{133,460.}{27} u^{11} - \frac{6,656,920.}{81} u^9 \right. \\
&\qquad \left. + \frac{14,308,240.}{27} u^7 - \frac{8,835,680.}{9} u^5 + 33,600.\, u^3 - \frac{515,200.}{9} u\right)
\end{aligned}\right\} \tag{27}$$

$$
\left.\begin{aligned}
S_0^1 &= -\left(\frac{3}{4}\right)^0 \cdot \frac{1}{2^1 \cdot 0!} \cdot u \\
S_1^1 &= -\left(\frac{3}{4}\right)^1 \cdot \frac{1}{2^4 \cdot 1!} (u^4 - 12u^2 + 12) \\
S_2^1 &= -\left(\frac{3}{4}\right)^2 \cdot \frac{1}{2^7 \cdot 2!} \left(u^7 - \frac{298}{9} u^5 + \frac{2{,}180.}{9} u^3 - \frac{920}{3} u\right) \\
S_3^1 &= -\left(\frac{3}{4}\right)^3 \cdot \frac{1}{2^{10} \cdot 3!} \left(u^{10} - \frac{190}{3} u^8 + \frac{10{,}360.}{9} u^6 - \frac{19{,}600.}{3} u^4 + \frac{25{,}200.}{3} u^2 - \frac{1{,}120}{3}\right) \\
S_4^1 &= -\left(\frac{3}{4}\right)^4 \cdot \frac{1}{2^{13} \cdot 4!} \left(u^{13} - \frac{308}{3} u^{11} + \frac{93{,}100.}{27} u^9 - \frac{135{,}712.}{3} u^7 + \frac{648{,}144.}{3} u^5 \right. \\
&\qquad \left. - \frac{804{,}160.}{3} u^3 + 11{,}200.\, u\right) \\
S_5^1 &= -\left(\frac{3}{4}\right)^5 \cdot \frac{1}{2^{16} \cdot 5!} \left(u^{16} - \frac{1{,}360}{9} u^{14} + \frac{218{,}480.}{27} u^{12} - \frac{15{,}465{,}280.}{81} u^{10} \right. \\
&\qquad + \frac{54{,}249{,}760.}{27} u^8 - \frac{226{,}822{,}400.}{27} u^6 + \frac{88{,}659{,}200.}{9} u^4 \\
&\qquad \left. - \frac{2{,}329{,}600.}{9} u^2 + \frac{1{,}030{,}400.}{9}\right)
\end{aligned}\right\} \quad (28)
$$

$$
\left.\begin{aligned}
S_0^2 &= \left(\frac{3}{4}\right)^0 \cdot \frac{1}{2^2 \cdot 0!} (u^2 - 2) \\
S_1^2 &= \left(\frac{3}{4}\right)^1 \cdot \frac{1}{2^5 \cdot 1!} (u^5 - 20u^3 + 60u) \\
S_2^2 &= \left(\frac{3}{4}\right)^2 \cdot \frac{1}{2^8 \cdot 2!} \left(u^8 - \frac{424}{9} u^6 + \frac{1{,}720.}{3} u^4 - 1{,}760.\, u^2 + \frac{1{,}840.}{3}\right) \\
S_3^2 &= \left(\frac{3}{4}\right)^3 \cdot \frac{1}{2^{11} \cdot 3!} \left(u^{11} - \frac{250}{3} u^9 + \frac{19{,}480.}{9} u^7 - \frac{61{,}040.}{3} u^5 \right. \\
&\qquad \left. + \frac{182{,}000.}{3} u^3 - \frac{101{,}920.}{3} u\right) \\
S_4^2 &= \left(\frac{3}{4}\right)^4 \cdot \frac{1}{2^{14} \cdot 4!} \left(u^{14} - \frac{386}{3} u^{12} + \frac{154{,}084.}{27} u^{10} - 107{,}304.\, u^8 + \frac{2{,}548{,}112.}{3} u^6 \right. \\
&\qquad \left. - \frac{7{,}285{,}600.}{3} u^4 + 1{,}619{,}520.\, u^2 - 22{,}400.\right) \\
S_5^2 &= \left(\frac{3}{4}\right)^5 \cdot \frac{1}{2^{17} \cdot 5!} \left(u^{17} - \frac{1{,}648}{9} u^{15} + \frac{332{,}720.}{27} u^{13} - \frac{31{,}195{,}840.}{81} u^{11} \right. \\
&\qquad + \frac{472{,}054{,}880.}{81} u^9 - \frac{364{,}939{,}520.}{9} u^7 \\
&\qquad \left. + \frac{995{,}948{,}800.}{9} u^5 - \frac{711{,}603{,}200.}{9} u^3 + \frac{10{,}348{,}800.}{9} u\right)
\end{aligned}\right\} \quad (29)
$$

$$
\left.\begin{aligned}
S_0^3 &= -\left(\frac{3}{4}\right)^0 \cdot \frac{1}{2^3 \cdot 0!}\,(u^3 - 6u) \\
S_1^3 &= -\left(\frac{3}{4}\right)^1 \cdot \frac{1}{2^6 \cdot 1!}\,(u^6 - 30u^4 + 180u^2 - 120) \\
S_2^3 &= -\left(\frac{3}{4}\right)^2 \cdot \frac{1}{2^9 \cdot 2!}\left(u^9 - \frac{568.}{9}u^7 + \frac{3{,}416.}{3}u^5 - \frac{19{,}040.}{3}u^3 + \frac{22{,}960.}{3}u\right) \\
S_3^3 &= -\left(\frac{3}{4}\right)^3 \cdot \frac{1}{2^{12} \cdot 3!}\left(u^{12} - \frac{316}{3}u^{10} + \frac{32{,}980.}{9}u^8 - \frac{455{,}840.}{9}u^6 + \frac{792{,}400.}{3}u^4\right. \\
&\qquad \left. - \frac{1{,}193{,}920.}{3}u^2 + \frac{203{,}840.}{3}\right) \\
S_4^3 &= -\left(\frac{3}{4}\right)^4 \cdot \frac{1}{2^{15} \cdot 4!}\left(u^{15} - \frac{470}{3}u^{13} + \frac{237{,}460.}{27}u^{11} - \frac{5{,}978{,}888.}{27}u^9 + \frac{7{,}698{,}704.}{3}u^7\right. \\
&\qquad \left. - \frac{37{,}862{,}944.}{3}u^5 + \frac{63{,}143{,}360.}{3}u^3 - 6{,}500{,}480.\,u\right) \\
S_5^3 &= -\left(\frac{3}{4}\right)^5 \cdot \frac{1}{2^{18} \cdot 5!}\left(u^{18} - \frac{1{,}954.}{9}u^{16} + \frac{481{,}040.}{27}u^{14} - \frac{57{,}148{,}000.}{81}u^{12}\right. \\
&\qquad + \frac{128{,}707{,}040.}{9}u^{10} - 145{,}449{,}920.\,u^8 + \frac{6{,}105{,}102{,}080.}{9}u^6 \\
&\qquad \left. - 1{,}185{,}676{,}800.\,u^4 + 475{,}552{,}000.\,u^2 - \frac{20{,}697{,}600.}{9}\right)
\end{aligned}\right\} \quad (30)
$$

These polynomials may be expressed in terms of their roots as follows:

$$
\left.\begin{aligned}
S_0^0 &= \left(\frac{3}{4}\right)^0 \cdot \frac{1}{2^0 \cdot 0!} = 1 \\
S_1^0 &= \left(\frac{3}{4}\right)^1 \cdot \frac{1}{2^3 \cdot 1!}\,(u^2 - {}_1a_1^2)u \\
S_2^0 &= \left(\frac{3}{4}\right)^2 \cdot \frac{1}{2^6 \cdot 2!}\,(u^2 - {}_2a_1^2)(u^2 - {}_2a_2^2)(u^2 - {}_2a_3^2) \\
S_3^0 &= \left(\frac{3}{4}\right)^3 \cdot \frac{1}{2^9 \cdot 3!}\,(u^2 - {}_3a_1^2)(u^2 - {}_3a_2^2)(u^2 - {}_3a_3^2)(u^2 - {}_3a_4^2)u \\
S_4^0 &= \left(\frac{3}{4}\right)^4 \cdot \frac{1}{2^{12} \cdot 4!}\,(u^2 - {}_4a_1^2)(u^2 - {}_4a_2^2)(u^2 - {}_4a_3^2))u^2 - {}_4a_4^2)(u^2 - {}_4a_5^2)(u^2 - {}_4a_6^2) \\
S_5^0 &= \left(\frac{3}{4}\right)^5 \cdot \frac{1}{2^{15} \cdot 5!}\,(u^2 - {}_5a_1^2)(u^2 - {}_5a_2^2)(u^2 - {}_5a_3^2)(u^2 - {}_5a_4^2) \\
&\qquad \cdot (u^2 - {}_5a_5^2)(u^2 - {}_5a_6^2)(u^2 - {}_5a_7^2)u
\end{aligned}\right\} \quad (27a)
$$

where

$$
\begin{aligned}
{}_1a_1 &= 2.4494897 & {}_5a_1 &= (.3489532) + i(.3470878)\\
{}_2a_1 &= .4386057 & {}_5a_2 &= (.3489532) - i(.3480878)\\
{}_2a_2 &= 2.0316884 & {}_3a_3 &= 1.7372969\\
{}_2a_3 &= 4.0976796 & {}_5a_4 &= 3.0039589\\
{}_3a_1 &= .3796034 & {}_5a_5 &= 4.3370220\\
{}_3a_2 &= 1.8957716 & {}_5a_6 &= 5.7988043\\
{}_3a_3 &= 3.5080532 & {}_5a_7 &= 7.5253341\\
{}_3a_4 &= 5.4119171 & & \\
{}_4a_1 &= (.2543301) + i(.1537223) & & \\
{}_4a_2 &= (.2543301) - i(.1537223) & & \\
{}_4a_3 &= 1.8043057 & & \\
{}_4a_4 &= 3.2025824 & & \\
{}_4a_5 &= 4.7320146 & & \\
{}_4a_6 &= 6.5530348 & &
\end{aligned}
\qquad (27b)
$$

$$
\begin{aligned}
S_0^1 &= -\left(\frac{3}{4}\right)^0 \cdot \frac{1}{2^1 \cdot 0!} \cdot u\\
S_1^1 &= -\left(\frac{3}{4}\right)^1 \cdot \frac{1}{2^4 \cdot 1!} (u^2 - {}_1b_1^2)(u^2 - {}_1b_2^2)\\
S_2^1 &= -\left(\frac{3}{4}\right)^2 \cdot \frac{1}{2^7 \cdot 2!} (u^2 - {}_2b_1^2)(u^2 - {}_2b_2^2)(u^2 - {}_2b_3^2)u\\
S_3^1 &= -\left(\frac{3}{4}\right)^3 \cdot \frac{1}{2^{10} \cdot 3!} (u^2 - {}_3b_1^2)(u^2 - {}_3b_2^2)(u^2 - {}_3b_3^2)(u^2 - {}_3b_4^2) - (u^2 - {}_3b_6^2)\\
S_4^1 &= -\left(\frac{3}{4}\right)^4 \cdot \frac{1}{2^{13} \cdot 4!} (u^2 - {}_4b_1^2)(u^2 - {}_4b_2^2)(u^2 - {}_4b_3)^2 u^2 - {}_4b_4^2)(u^2 - {}_4b_5^2)(u^2 - {}_4b_6^2)u\\
S_5^1 &= -\left(\frac{3}{4}\right)^5 \cdot \frac{1}{2^{16} \cdot 5!} (u^2 - {}_5b_1^2)(u^2 - {}_5b_2^2)(u^2 - {}_5b_3^2)(u^2 - {}_5b_4^2)\\
&\qquad \cdot (u^2 - {}_5b_5^2)(u^2 - {}_5b_6^2)(u^2 - {}_5b_7^2)(u^2 - {}_5b_8^2)
\end{aligned}
\qquad (28a)
$$

where

$$
\begin{aligned}
{}_1b_1 &= 1.0492952 & {}_5b_1 &= (.2418248) + i(.2241047)\\
{}_1b_2 &= 3.3013602 & {}_5b_2 &= (.2418248) - i(.2241047)\\
{}_2b_1 &= 1.2643058 & {}_5b_3 &= 1.3550222\\
{}_2b_2 &= 2.8715097 & {}_5b_4 &= 2.4746194\\
{}_2b_3 &= 4.8235956 & {}_5b_5 &= 3.6653883\\
{}_3b_1 &= .2146690 & {}_5b_6 &= 4.9464936\\
{}_3b_2 &= 1.3162830 & {}_5b_7 &= 6.3633569\\
{}_3b_3 &= 2.6799645 & {}_5b_8 &= 8.0460916\\
{}_3b_4 &= 4.2192654 & & \\
{}_3b_5 &= 6.0473332 & & \\
{}_4b_1 &= .2080355 & & \\
{}_4b_2 &= 1.3437754 & & \\
{}_4b_3 &= 2.5594485 & & \\
{}_4b_4 &= 3.8863697 & & \\
{}_4b_5 &= 5.3580087 & & \\
{}_4b_6 &= 7.1031509 & &
\end{aligned}
\qquad (28b)
$$

$$
\begin{aligned}
S_0^2 &= \left(\frac{3}{4}\right)^0 \cdot \frac{1}{2^2 \cdot 0!}\,(u^2 - {}_0c_1^2) \\
S_1^2 &= \left(\frac{3}{4}\right)^1 \cdot \frac{1}{2^5 \cdot 1!}\,(u^2 - {}_1c_1^2)(u^2 - {}_1c_2^2)u \\
S_2^2 &= \left(\frac{3}{4}\right)^2 \cdot \frac{1}{2^8 \cdot 2!}\,(u^2 - {}_2c_1^2)(u^2 - {}_2c_2^2)(u^2 - {}_2c_3^2)(u^2 - {}_2c_4^2) \\
S_3^2 &= \left(\frac{3}{4}\right)^3 \cdot \frac{1}{2^{11} \cdot 3!}\,(u^2 - {}_3c_1^2)(u^2 - {}_3c_2^2)(u^2 - {}_3c_3^2)(u^2 - {}_3c_4^2)(u^2 - {}_3c_5^2)u \\
S_4^2 &= \left(\frac{3}{4}\right)^4 \cdot \frac{1}{2^{14} \cdot 4!}\,(u^2 - {}_4c_1^2)(u^2 - {}_4c_2^2)(u^2 - {}_4c_3^2)(u^2 - {}_4c_4^2) \\
&\qquad \cdot (u^2 - {}_4c_5^2)(u^2 - {}_4c_6^2)(u^2 - {}_4c_7^2) \\
S_5^2 &= \left(\frac{3}{4}\right)^5 \cdot \frac{1}{2^{17} \cdot 5!}\,(u^2 - {}_5c_1^2)(u^2 - {}_5c_2^2)(u^2 - {}_5c_3^2)(u^2 - {}_5c_4^2) \\
&\qquad \cdot (u^2 - {}_5c_5^2)(u^2 - {}_5c_6^2)(u^2 - {}_5c_7^2)(u^2 - {}_5c_8^2)u
\end{aligned}
\tag{29a}
$$

where

$$
\begin{aligned}
{}_0c_1 &= 1.4142136 \\
{}_1c_1 &= 1.9171449 \\
{}_1c_2 &= 4.0403657 \\
{}_2c_1 &= .6313067 \\
{}_2c_2 &= 2.0037771 \\
{}_2c_3 &= 3.5825660 \\
{}_2c_4 &= 5.4646739 \\
{}_3c_1 &= .8494710 \\
{}_3c_2 &= 2.0184280 \\
{}_3c_3 &= 2.2513124 \\
{}_3c_4 &= 4.8450276 \\
{}_3c_5 &= 6.6205812 \\
{}_4c_1 &= .1188661 \\
{}_4c_2 &= .9592981 \\
{}_4c_3 &= 2.0211776 \\
{}_4c_4 &= 3.2020235 \\
{}_4c_5 &= 4.4904315 \\
{}_4c_6 &= 5.9224984 \\
{}_4c_7 &= 7.6258907
\end{aligned}
\qquad
\begin{aligned}
{}_5c_1 &= .1218601 \\
{}_5c_2 &= 1.0268945 \\
{}_5c_3 &= 2.0187355 \\
{}_5c_4 &= 3.0954378 \\
{}_5c_5 &= 4.2501778 \\
{}_5c_6 &= 5.4973378 \\
{}_5c_7 &= 6.8810771 \\
{}_5c_8 &= 8.5294059
\end{aligned}
\tag{29b}
$$

$$
\left.\begin{aligned}
S_0^3 &= -\left(\frac{3}{4}\right)^0 \cdot \frac{1}{2^3 \cdot 0!}\,(u^2 - {}_0d_1^2)u \\
S_1^3 &= -\left(\frac{3}{4}\right)^1 \cdot \frac{1}{2^6 \cdot 1!}\,(u^2 - {}_1d_1^2)(u^2 - {}_1d_2^2)(u^2 - {}_1d_3^2) \\
S_2^3 &= -\left(\frac{3}{4}\right)^2 \cdot \frac{1}{2^9 \cdot 2!}\,(u^2 - {}_2d_1^2)(u^2 - {}_2d_2^2)(u^2 - {}_2d_3^2)(u^2 - {}_2d_4^2)u \\
S_3^3 &= -\left(\frac{3}{4}\right)^3 \cdot \frac{1}{2^{12} \cdot 3!}\,(u^2 - {}_3d_1^2)(u^2 - {}_3d_2^2)(u^2 - {}_3d_3^2)(u^2 - {}_3d_4^2)(u^2 - {}_3d_5^2)(u^2 - {}_3d_6^2) \\
S_4^3 &= -\left(\frac{3}{4}\right)^4 \cdot \frac{1}{2^{15} \cdot 4!}\,(u^2 - {}_4d_1^2)(u^2 - {}_4d_2^2)(u^2 - {}_4d_3^2)(u^2 - {}_4d_4^2) \\
&\qquad \cdot (u^2 - {}_4d_5^2)(u^2 - {}_4d_6^2)(u^2 - {}_4d_7^2)u \\
S_5^3 &= -\left(\frac{3}{4}\right)^5 \cdot \frac{1}{2^{18} \cdot 5!}\,(u^2 - {}_5d_1^2)(u^2 - {}_5d_2^2)(u^2 - {}_5d_3^2)(u^2 - {}_5d_4^2)(u^2 - {}_5d_5^2) \\
&\qquad \cdot (u^2 - {}_5d_6^2)(u^2 - {}_5d_7^2)(u^2 - {}_5d_8^2)(u^2 - {}_5d_9^2)
\end{aligned}\right\} \tag{30a}
$$

where

$$
\left.\begin{aligned}
{}_0d_1 &= 2.4494897 & {}_5d_1 &= .06996792 \\
{}_1d_1 &= .8721548 & {}_5d_2 &= .74347164 \\
{}_1d_2 &= 2.6716981 & {}_5d_3 &= 1.6172947 \\
{}_1d_3 &= 4.7012099 & {}_5d_4 &= 2.5969881 \\
{}_2d_1 &= 1.2851870 & {}_5d_5 &= 3.6531245 \\
{}_2d_2 &= 2.6705800 & {}_5d_6 &= 4.7836803 \\
{}_2d_3 &= 4.2158628 & {}_5d_7 &= 6.0053552 \\
{}_2d_4 &= 6.0459828 & {}_5d_8 &= 7.3627757 \\
{}_3d_1 &= .4416455 & {}_5d_9 &= 8.9827503 \\
{}_3d_2 &= 1.4593267 & & \\
{}_3d_3 &= 2.6442323 & & \\
{}_3d_4 &= 3.9534818 & & \\
{}_3d_5 &= 5.4126795 & & \\
{}_3d_6 &= 7.1476965 & & \\
{}_4d_1 &= .6286818 & & \\
{}_4d_2 &= 1.5554091 & & \\
{}_4d_3 &= 2.6191473 & & \\
{}_4d_4 &= 3.7795034 & & \\
{}_4d_5 &= 5.0403263 & & \\
{}_4d_6 &= 6.4419739 & & \\
{}_4d_7 &= 8.1119438 & &
\end{aligned}\right\} \tag{30b}
$$

The polynomial $S_n^m(u)$ satisfies the recurrence formula

$$
\begin{aligned}
16S_{n+2}^{m+3} &+ 8u(S_{n+2}^{m+2} + S_{n+1}^{m+3}) + 8(n+m+4)(S_{n+2}^{m+1} + S_{n+1}^{m+2}) \\
&+ u^2(S_{n+1}^{m+2} + S_n^{m+3}) + (2n+2m+7)u(S_{n+1}^{m+1} + S_n^{m+2}) \\
&+ (n+m+2)(n+m+4)(S_{n+1}^{m} + S_n^{m+1}) = 0.
\end{aligned} \tag{31}
$$

The notation has been changed somewhat from that given in the paper mentioned in footnote (1) above. The functions $P_n(u)$ and $Q_n(u)$ of that paper are related to $\Psi_n(u)$ by

$$P_n(u) = -\Psi_n'(u)$$

and

$$Q_n(u) = -\Psi_n''(u).$$

This reversal in sign has been made so that in all three forms of the seismic disturbance, displacement, velocity, and acceleration, the first motion is positive. The wavelet-form functions may be written

$$\mathcal{U}(u \mid X) \equiv \sum_{n=0}^{\infty} \left(\frac{2}{X}\right)^{n/2} \Psi_n'(u) \tag{32}$$

$$\mathcal{V}(u \mid X) \equiv \sum_{n=0}^{\infty} \left(\frac{2}{X}\right)^{n/2} \Psi_n''(u) \tag{33}$$

$$\mathcal{W}(u \mid X) \equiv \sum_{n=0}^{\infty} \left(\frac{2}{X}\right)^{n/2} \Psi_n'''(u). \tag{34}$$

These functions represent the forms of the earth displacement, velocity, and acceleration type wavelet respectively. Here again the sign has been reversed—the script $\mathcal{U}$; $\mathcal{V}$ being the negative of the italic U; V of the previous paper. In the present notation the solution with X held constant and the time allowed to vary, describes the conventional motion of the trace of a seismograph, with time advancing from left to right and the first motion upwards. Also, in the present notation, the solution with T held constant and X allowed to vary gives the wave profile in the earth with the wave advancing from left to right and the first motion positive.

It may be seen from these solutions that for plane waves the wavelet amplitude decays as $(2/X)^{2/2}$; $(2/X)^{3/2}$; $(2/X)^{4/2}$ for the displacement, velocity, and acceleration wavelet types respectively. For spherical waves spreading out from a center the wavelet amplitude must decay as $(2/R)^{4/2}$; $(2/R)^{5/2}$; $(2/R)^{6/2}$ for these respective forms, wherein R is the numerical radial distance defined by

$$R \equiv \frac{\omega_0 r}{c}$$

in which r is the true distance.

GEOPHYSICAL SURVEY OF THE ARKANSAS BAUXITE REGION*

MARK C. MALAMPHY,† AND JAMES L. VALLELY‡

ABSTRACT

Magnetic and gravimetric surveys were conducted over an area of approximately 1400 square miles in the bauxite district of central Arkansas. The primary purpose of these surveys was to discover any possible buried and hitherto unknown syenite masses favorable for the occurrence of bauxite and to determine the approximate position of the buried flanks of the known syenite masses which might offer conditions favorable for the discovery of new ore bodies.

These surveys indicated that the various syenite outcrops are domes or bosses on a large batholith and that other similar domes occur on the batholith but do not outcrop.

Drilling on the local geophysical anomalies proved the presence of 10 buried domes, but only 2 were found to project above the upper surface of the Midway clays, a requisite of conditions favorable for the occurrence of bauxite ore bodies.

The geophysical data indicated the approximate configuration of the buried flanks of the known syenite outcrops, and the portions of these flanks that project above the Midway have now been outlined more accurately by drilling.

The geophysical surveys have produced evidence permitting the elimination of a large area as unfavorable for the occurrence of bauxite.

Magnetic surveys extending along the Midway-Wilcox contact from Gurdon in Clark County on the southwest to Searcy in White County on the northeast have proved the improbability of the existence of other syenite masses similar to those found in Pulaski and Saline Counties. A detailed magnetic survey of the Magnet Cove area in Hot Spring County has proved that the syenite mass exposed in that locality is an isolated intrusion and entirely unrelated to those of Pulaski and Saline Counties. This syenite mass does not occur under conditions believed to be favorable for the occurrence of bauxite.

INTRODUCTION

In the three years preceding 1941, more than 70 percent of the bauxite utilized in the manufacture of aluminum in the United States was imported from foreign sources, principally South America. Previous to 1941, Arkansas produced more than 95 percent of the bauxite mined in this country and had an equally large percentage of the estimated domestic reserves.

Soon after the start of the war, consumption of aluminum had increased to such an extent that it was becoming increasingly difficult to import enough bauxite to meet the needs of the aluminum industry; it was obvious that the production of domestic bauxite would need to be increased and that additional reserves should be developed in this country.

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‡ Associate Mining Engineer, Bureau of Mines, Little Rock, Arkansas

Congress foresaw these conditions and passed the "Second Supplemental National Defense Act, 1941" approved October 28, 1941 (Public Law 282, 77th Cong. Chap. 460, 1st sess., H. R. 5788). This act authorized the Bureau of Mines and the Geological Survey to investigate the extent, mode of occurrence, and quality of bauxite and alunite ores and aluminum clays in the United States.

Plans for a program of exploration in Arkansas under the direction of Bureau of Mines engineers* were worked out in detail during the closing months of 1941. They provided for extensive geophysical surveys by magnetic and gravimetric methods, to be followed by core drilling. The magnetic work was begun on December 19, 1941, and terminated on December 31, 1942. The gravimetric work began on January 28 and ended on November 30, 1942. The first drill started working on May 1, 1942, and by October of that year six drills were working. During 1943 the tempo of the work was stepped up, and by November the number of drills had been increased to 20. Drilling is still in progress and will continue until the entire area believed to be favorable for the occurrence of bauxite has been thoroughly investigated.

Members of a field party of the Federal Geological Survey cooperated with the Bureau of Mines throughout the course of the drilling conducted in the investigation of Arkansas bauxite deposits.

This report is designed to describe the geophysical work accomplished under this program, present the results of the geophysical surveys, and correlate them with the results of the drilling.

GEOLOGY OF BAUXITE IN ARKANSAS[1]

In Arkansas, bauxite and bauxitic clay are found at the unconformity at the base of a group of early Tertiary (Eocene) nonmarine sedimentary rocks (the Wilcox group), which dip gently southeastward and lie unconformably upon the eroded surface of (1) earlier Tertiary (Paleocene) marine sedimentary rocks (the Midway group), (2) folded, steeply dipping, somewhat metamorphosed Paleozoic sedimentary rocks, and (3) Cretaceous (?) intrusive igneous rocks (nephelite syenite). (See geologic map, Fig. 1.)

* J. R. Thoenen, District Engineer, and M. C. Malamphy, Project Engineer.

[1] Thoenen, J. R., Malamphy, M. C., and Bryson, R. P., *Arkansas Bauxite Exploration*. Bureau of Mines War Minerals Report No. 202, May, 1943.

See also Bureau of Mines War Minerals Reports on Bauxite Investigations in Arkansas. Nos. 62, 77, 96, 98, 114, 117, 118, 255 and others submitted, or in preparation, and not yet published.

Arkansas bauxite is related genetically to the intrusive masses of nephelite syenite, an igneous rock composed essentially of feldspars and feldspathoid minerals. One large mass of syenite is exposed just south of Little Rock in Pulaski County and other outcrops are found near Bauxite in Saline County. Most of the bauxite known in Arkansas is found adjacent to these exposures and forms an irregular blanket over parts of the eroded surface of the syenite and the adjacent Midway clay beneath a blanket of Wilcox sediments that is several hundred feet thick in many places.

The baxite was developed by weathering and other natural processes in a residual soil mantle resulting from the decomposition of the exposed syenite. Some of the bauxite, such as the "granitic" type mined in Saline County, remained where it was developed in the soil mantle on the syenite. Most of the bauxite, however, was subsequently transported, in some instances only a short distance, to its present position. The resulting bodies of bauxite may be compared with deposits of talus or soil material, alluvial fan and apron deposits, or alluvial valley fill.

Deposition of the transported bauxite and formation of the ore bodies occurred at or near a change of slope or gradient on the old land surface, commonly a line between hard and soft rocks—the buried contact between the nephelite syenite and the Midway clay. In general, it is true that the locus of deposition of transported bauxite ore bodies lies along the buried syenite-Midway contact. Isolated occurrences of bauxite, commonly thin and of low grade, are found also some distance from the syenite, but bodies of ore are not to be expected at such localities.

Although outcrops of bauxite are found at many places in the district, the ore bodies directly associated with these outcrops have been investigated by the mining companies and have been mined out, are in process of being mined, or constitute known reserves of the mining companies. Those that remained to be discovered (December 1941) were buried beneath a cover of Wilcox sediments, were not directly associated with any known outcrops of bauxite, and had no direct expression of their location in surface geologic features.

The best hitherto published map of the bauxite district was prepared by M. N. Bramlette[2] in connection with his study of the Arkansas bauxite district.*

[2] Bramlette, M.N., *Geology of the Arkansas Bauxite Region.* Information Circular No. 8. Arkansas Geological Survey, Little Rock, Arkansas, 1936.

* The U. S. Geological Survey has recently released (after this manuscript was pre-

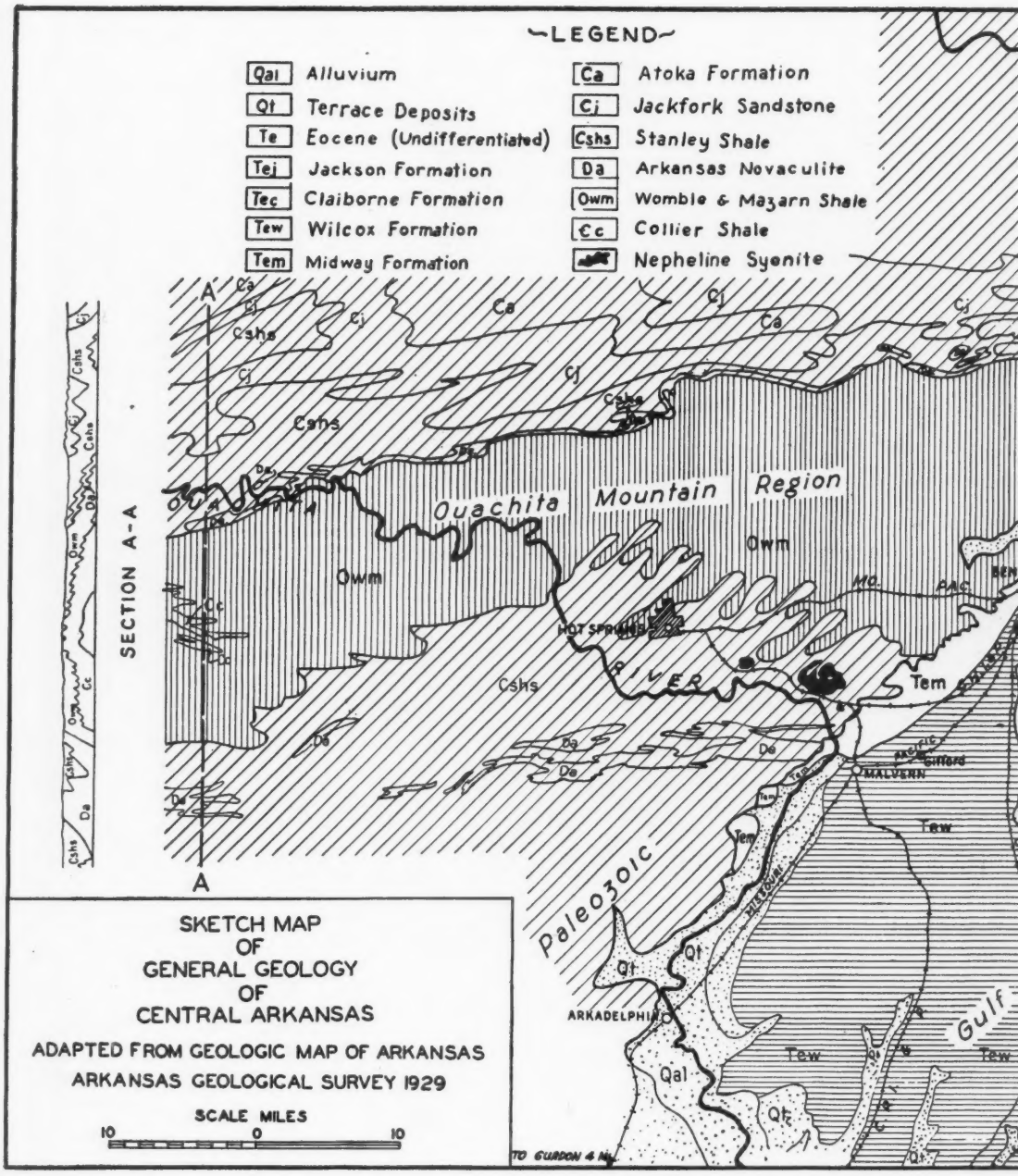
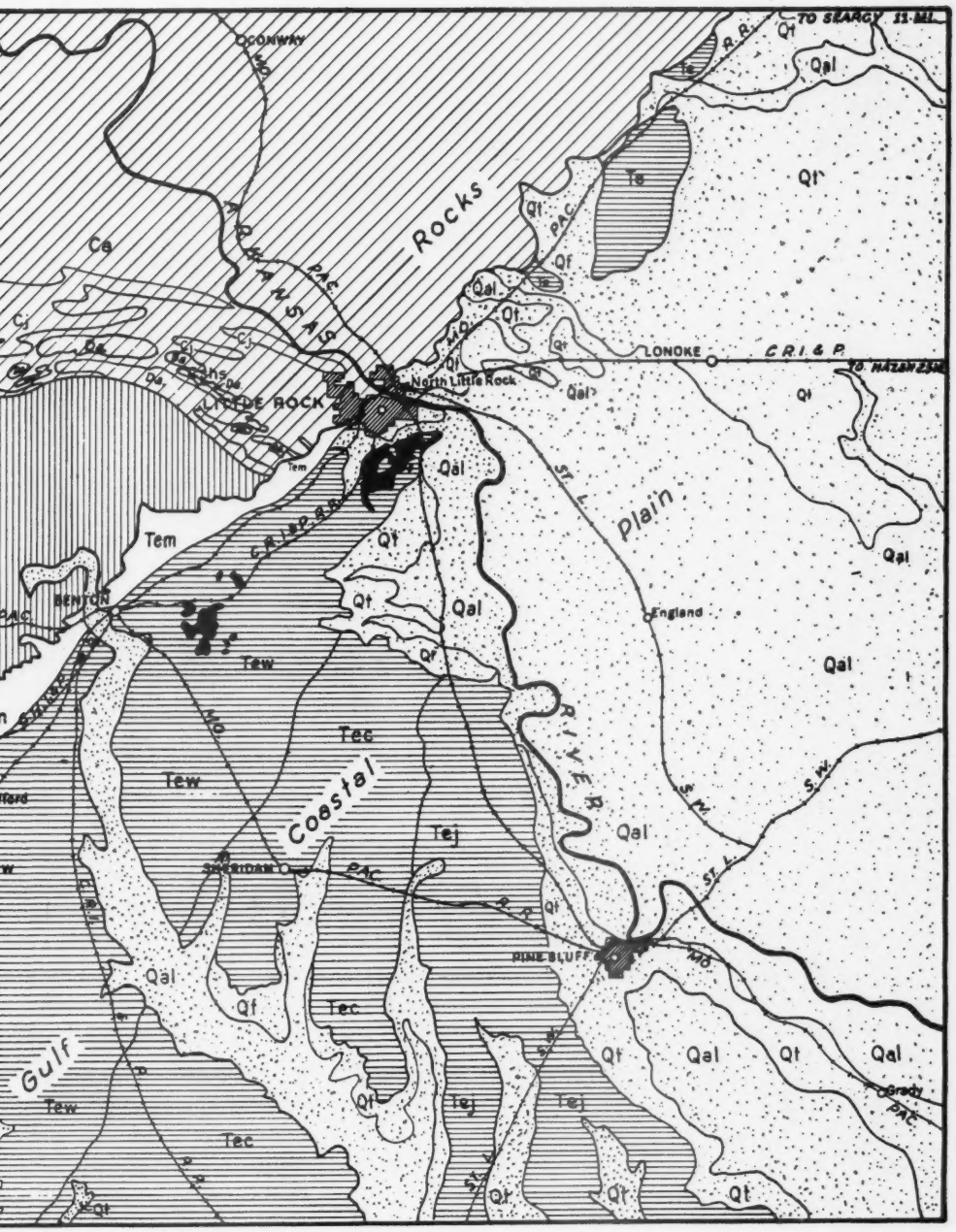


FIG. 1. Sketch map of general geology of



geology of Central Arkansas.

AREA SELECTED FOR INVESTIGATION

Summing up what was known of the geology of the occurrence of bauxite in Arkansas, it was decided that the primary prerequisite was the presence of nephelite syenite intrusions which protrude above the ancient surface of the Midway clays. Since it was probable that all outcrops of bauxite had been investigated, it was necessary to assume further that any new deposits would be hidden beneath a cover of Wilcox sediments.

This automatically restricted the region to be investigated to an elongated area extending northeast-southwest along, and southeast of, the contact between the Tertiary rocks of the Gulf Coastal Plain and the Paleozoic rocks of the Ouachita Mountain region. This contact is shown on the geologic map (Fig. 1) and the area selected extended from the town of Gurdon, a short distance southwest of Arkadelphia, to the town of Searcy, some 50 miles northeast of Little Rock, along the Missouri Pacific Railroad. Both towns are slightly beyond the limits of the map shown.

The total length of the area selected is approximately 135 miles. At its widest point it extends southeast of Benton to Sheridan, a distance of approximately 20 miles, and tapers to a width of less than 5 miles at each extremity.

It is an area of gently rolling hills with topographic relief seldom exceeding 200 feet. Second-growth hardwoods and short-leaf pine cover the region, except for small areas cleared for cultivation or mining.

The northeastern part of the region drains easterly through minor tributaries of the Arkansas River. Similar streams drain the southwestern part southerly by way of the Saline River.

The area is well-served by paved highways and improved gravel roads, while unimproved county roads provide additional access at all times except in periods of continuous rains.

APPLICABILITY OF GEOPHYSICAL METHODS

Bauxite does not possess any outstanding geophysical property that will permit its direct investigation by known geophysical methods. However, the syenite with which the bauxite is associated does

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pared) a new map of the Arkansas Bauxite District dated February 1, 1944, to which the following reference may be given:

U. S. Geological Survey, *Map Showing Surface Geology, Subsurface Contours Drawn on the Post-Midway Surface, and Bauxite Mines, Arkansas Bauxite District.* U. S. Dept. of the Interior, Geological Survey, February 1, 1944.

possess such properties, and geophysical methods are available that will permit the investigation of the configuration of parts of the old land surface. Therefore, geophysical methods may be used to locate hidden intrusives and map the topography of the ancient land surface and thus serve as indirect methods of prospecting for bauxite in Arkansas.

Of the various geophysical methods of prospecting in common use today, four may be considered as applicable to the problem of prospecting for new bauxite deposits in Arkansas. The magnetic and gravimetric methods are particularly useful in the investigation of hidden extensions of the known syenite masses and in the discovery of hitherto unknown masses of igneous rocks. The seismic and resistivity methods are capable of procuring information relative to the topography of the bedrock.

The syenites of this region possess a magnetic susceptibility considerably greater than that of the Paleozoic rocks into which they are intruded and that of the overlying Tertiary rocks.

The presence of the igneous rocks disturbs the normal distribution of the earth's magnetic field, and the resulting magnetic anomalies created may be mapped and correlated with the position and form of the igneous rocks. Polarization phenomena complicate the magnetic picture, and great care must be used in the interpretation of the results, particularly in those areas where the syenite is close to the surface. Minor changes in the mineral composition of the syenite often result in important changes in the magnetic susceptibility and therefore in the magnitude of the magnetic anomalies.

The difference between the densities of the syenites and some of the phases of the Paleozoic rocks of the Ouachita uplift are so small as to make it practically impossible to distinguish between their effects on the earth's gravitational field. The density difference between these rocks as a group and the Tertiary rocks making up the overburden is quite appreciable, and it is therefore to be expected that the gravity data would reflect the topography of the buried Paleozoic rocks and/or the syenite, whichever is higher. The regional southeastward dip of the Paleozoic rocks, plus changes in density in the truncated portions of folded formations, undoubtedly will bring complications into the picture that will make interpretation of the data more difficult.

The relative shallowness of the syenite and Paleozoic basement in the more promising portions of the bauxite region preclude the use of the seismic reflection method, which seldom works satisfactorily for

depths of less than 1000 feet. However, the seismic refraction method could be used for these shallow depths and, if seismic depth determinations were made at sufficiently close intervals, would furnish a reasonably accurate picture of the configuration of the old land surface. Unfortunately, the velocities of propagation of seismic waves in the syenite, the bauxite, the Paleozoic rocks, and even in the Midway limestone are of the same order of magnitude and always show considerable variations. It is therefore difficult, if not impossible, to determine with any degree of accuracy the type of rock to which the depth determinations are referred. As a result, subsurface contour maps based on refraction seismograph data would show only the ancient land topography, regardless of whether the bedrock consists of syenite, Paleozoic rocks, or perhaps (in some instances) Midway limestones.

Regardless of its character, the bedrock is more compact than the over-lying Tertiary sands, clays, and lignites, and should therefore be expected to exhibit higher electrical resistivity. This makes it possible to apply the earth-resistivity method to the mapping of the subsurface topography of the bedrock. This method becomes cumbersome and less accurate for depths much in excess of 100 feet, and the results obtained for greater depths would generally be greatly inferior to those obtained by the seismic refraction method.

GEOPHYSICAL PROGRAM OF THE BUREAU OF MINES

In the preparation of a program of exploration for bauxite in Arkansas, all available data relative to the geology and geophysical properties of the rocks were studied; in addition, the relative economy and rapidity of the various geophysical methods, as compared to core drilling, were taken into consideration.

The magnetic method was chosen for a first reconnaissance because of its rapidity and economy. A previous magnetic survey by Noel H. Stearn[3] had shown considerable promise, and it was believed that a new survey using more precise instruments, and with observations taken at closer station intervals, would furnish additional information of value in the more important part of the area surveyed by Stearn. This also appeared to be the preferred method for extending the area under investigation along the Tertiary-Palezoic contact, both northeast and southwest of the proved bauxite region.

[3] Stearn, Noel H., *A Geomagnetic Survey of the Bauxite Region in Central Arkansas.* Bul. 5, Arkansas Geological Survey, Little Rock, Arkansas, 1930.

The gravimetric method (gravity meter) was selected as a follow-up, to be used primarily in the more favorable areas selected on the basis of the magnetic survey. The results of an experimental survey over a small area conducted by the Brown Geophysical Company[4] in October 1941 were available and appeared to show considerable promise. It was therefore expected that an extensive gravity survey would aid considerably in clarifying the effects of magnetic polarization on the recorded magnetic anomalies. Unfortunately, it was found later that the regional effect of the Paleozoic basement rocks on the gravimetric data was equally as complex as the effect of polarization phenomena on the magnetic data.

The utilization of the seismic method was not given serious consideration in the original program of exploration for two reasons; first, the results of a reconnaissance seismic refraction survey made for the Reynolds Mining Company[5,6] were available, and second, it was believed that the cost of a seismic survey made in sufficient detail to be of real value would approach the cost of core drilling the same area.

No consideration was given to the possible use of the resistivity method because it was believed that the results would not be accurate enough to justify their cost.

The program of exploration decided upon consisted of:

1. Magnetic reconnaissance survey covering the entire region selected for exploration as described in the foregoing pages.
2. Gravimetric survey of the more promising areas as indicated by the magnetic survey and by geological information.
3. Core drilling to check the results of the magnetic and gravimetric surveys and geologic data gathered by the Geological Survey.
4. Initiation of geophysical surveys and drilling under contracts with reputable firms, to be directed and supervised by Bureau of Mines engineers.

Invitations for bids for the magnetic work were sent out in November 1941. The contract was let to Heiland Research Corporation of

[4] Brown Geophysical Company. *Report on a Gravity Meter Survey of a Portion of the Bauxite Region of Central Arkansas.* October 21, 1941 (Inedit).

[5] National Geophysical Company. *Seismic Survey Report on Little Rock Area, Submitted to Reynolds Mining Corporation.* October, 1941 (Inedit).

[6] Gillin, J. A., Shock, Lorenz and Alcock, E. D., *An Application of Seismic Surveying to the Location of Bauxite in Arkansas.* GEOPHYSICS, Vol. 7, No. 4, October, 1942.

Denver and the survey initiated on December 19, 1941, and completed on December 31, 1942. During this period, 11,104 magnetic observations were made, consisting of 8928 effective stations plus 2176 base stations and check readings. These magnetic observations were distributed over a total area of 1220 square miles, giving an over-all average station density of 7.3 stations per square mile. In the central part of the area surveyed (that is, in the most favorable part of the region) the average station density was 12 stations per square mile, while in the northeast and southwest extensions the average station density was 3.75. The observed changes in magnetic intensity in the areas northeast and southwest of the proved bauxite region were small in magnitude and quite regular so that the reduced station density was quite permissible. On the other hand, an extension of the area to include the syenite outcrop in the vicinity of Magnet Cove showed such pronounced variations in magnetic intensity that it was necessary to make very detailed observations, and the average station density was approximately 300 stations per square mile.

Invitations for bids for the gravimetric survey were sent out in January 1942, and the contract was let to Heiland Research Corporation and work begun on January 28, 1942. For the purpose of speeding the work, a second gravity-meter party was contracted for and put in service on July 9, 1942, and the survey was continued until November 30, 1942. During this period, 9009 gravity observations were made, consisting of 5185 effective new stations plus 3824 base and check stations. These gravity-meter observations were distributed over a total area of 505 square miles, corresponding to an average station density of 10.25 stations per square mile.

Adding the total area surveyed by each method and subtracting the 320 square miles over which both methods were applied leaves a grand total of approximately 1405 square miles surveyed by one or both of the geophysical methods.

GEOPHYSICAL INSTRUMENTS USED

The magnetic observations were made with Askania "Schmidt-Lloyd" magnetic field balances for the vertical intensity described in detail by Joyce.[7] They were equipped with new type temperature compensated magnetic systems adjusted to a sensitivity of approxi-

[7] Joyce, J. Wallace. *Manual on Geophysical Prospecting with the Magnetometer*, U. S. Bureau of Mines, March, 1937.

mately 30 gammas* per division. Their calibration was checked at frequent intervals by means of a Helmholtz coil designed for that purpose. The mean error of the observations was of the order of magnitude of 2 gammas, an accuracy far greater than that of the various corrections which had to be applied in the reduction of the field data.

The gravimetric observations were made with Frost gravity-meters (or gravimeters) described in some detail in the pamphlet listed below.[8]

The sensitivity of the meters used on this survey was slightly better than 0.1 milligal** per division. The average error of any instrument observation is plus or minus 0.03 milligal.

When operating along the highway, the instrument was carried in a specially adapted sedan-type automobile equipped with a tripod which could be lowered or raised through a hole in the floor of the car. This provision permitted very rapid operation. For cross-country operations, the instrument was carried in a web-basket shoulder pack, and a small lightweight tripod was used.

FIELD PROCEDURE

The field procedures followed in the course of both the magnetic and the gravimetric surveys were quite similar. Base stations were established at conveniently located points, preferably near junctions of roads for greater accessibility from various directions. All these base stations, separated by an average distance of approximately 4 miles, were tied together by a series of interlocking "loops" or closed geophysical traverses, and their relative values were adjusted in a manner similar to that commonly used for the adjustment of closed transit or level traverses.

Field stations were also read in closed loops, taking off from a previously established base station and returning to the same or a nearby, previously adjusted, base station.

The first base station established was assigned an arbitrary value, and, as the interlocking network of base and field stations was expanded over the area, all stations were automatically referred to the arbitrary geophysical datum of the first base.

Observations were first made along transitable roads, and the

* 100,000 gammas = 1 Oersted, the C.G.S. unit of magnetic field intensity.

[8] Frost, C. H. *Exploring for Oil, Gas and Minerals with the Gravity Meter.* C. H. Frost Gravimetric Surveys, Tulsa, Oklahoma.

** 1000 Milligals = 1 Gal (after Galileo) = acceleration of 1 Cm/Sec/Sec.

instruments and personnel were transported by automobile. Later, as the geophysical picture became more complete, observations were made along cross-country traverses in those areas where closer control and greater detail were deemed necessary or desirable.

Maps made by the U. S. Geological Survey,[9] Arkansas Forestry Commission and the U. S. Engineers as well as A.A.A. aerial photographs were available for the greater part of the area surveyed in detail. When traversing was done along the roads, distances were measured by automobile odometer and station locations corrected by reference to crossroads, streams, bench marks, section lines and other specific markers which could be definitely identified on the maps and photographs. In cross-country work, the directions and distances of the traverses were determined by hand compasses and pacing (magnetic survey) or transit and stadia (gravimetric survey), and checked by reference to the topographic maps and aerial photographs. This procedure greatly speeded up the field work, prevented any accumulation of errors in horizontal control, and permitted the determination of latitude corrections with an accuracy at least comparable with the observational accuracy of the instruments used.

It is believed that few, if any, station locations are in error by as much as 200 feet in a north-south direction, which would correspond to approximately 0.04 milligal latitude correction.

Thousands of drill holes have been surveyed and tied into many of the gravity stations and in no case has any evidence been found of errors in locations greater than indicated above.

Geophysical observations were normally taken at quarter-mile intervals along the traverses, both along highways and cross-country, but many of the traverses were separated by greater distances. The spacing of the magnetic stations in the northeast and southwest extensions of the principal part of the area was increased to one half mile, and in some cases to one mile. The regularity of the magnetic field in these areas made this procedure quite permissible. On the other hand, the detailed observations in the Magnet Cove area, north of Malvern, required a very close spacing of the observation points.

[9] Alexander Quadrangle 1:48,000, 1941
Little Rock Quadrangle 1:24,000, 1935
Sweet Home Quadrangle 1:24,000, 1935
Woodson Quadrangle 1:24,000, 1942
Scott Quadrangle 1:31,680, 1942
Benton Quadrangle 1:48,000, 1938

CORRECTIONS APPLIED TO FIELD DATA

The magnetic data were corrected for latitude, diurnal variation, and base control. The vertical component of the earth's magnetic field increases from zero at the magnetic equator to its maximum value at the north magnetic pole. To compensate for this effect, an east-west (magnetic) base line was assumed at the southern limit of the area, and a correction of 13.2 gammas per mile distance from the base line was applied to the observed value for each station.

The intensity of the earth's magnetic field at any given point varies from hour to hour. Although the hourly changes are repeated every day, they do not follow exactly the same pattern, and it is impossible to predict just what the change will be at any particular time. This regularly recurring change in magnetic intensity is called the diurnal variation.

The diurnal variation may be determined by maintaining a magnetic field balance on a fixed station and taking observations at fixed time intervals and plotting a curve from the observed data showing variations in intensity as a function of time. This procedure was followed when cross-country traverses were being run. Where the diurnal variation is small in comparison to the magnitude of the observed anomalies, less precision in this correction is required. Under such conditions it is quite permissible to determine the diurnal variation by making check readings on any given base station at intervals not exceeding 2 hours and plotting a curve from these data. This procedure was followed when traversing was done along highways and an automobile was used to transport the instrument and observer.

The base-control correction has for its main purpose the detection of any minor changes in the position of the center of gravity of the magnetic system due to shocks in transport, etc. Such dislocations cause a change in the scale reading of the instrument corresponding to a given intensity. If an instrument recording at a fixed base station is used to determine the diurnal variation, repeat observations at some base station 3 or 4 times a day will be sufficient to determine the base-control correction; if each instrument is used to determine its own diurnal variation, the base-control is automatically included in those data.

The gravimetric data were corrected for latitude, instrument drift and elevation. Because of the spheroidal shape of the earth, gravity gradually increases from the equator to the poles. For the latitude of central Arkansas the northward gravity gradient amounts to 1.02

milligals per mile. As was the case for the magnetic data, an east-west (astronomical) base line was assumed at the southern limit of the area, the distance of each station north of this base line determined, and the appropriate latitude correction applied.

Fatigue, the effects of minor shocks during transportation, and perhaps some incompletely compensated temperature or barometric effects combined to cause the scale reading corresponding to a given intensity of gravity to change gradually during the day's work. This instrument drift sometimes reaches an appreciable magnitude and must be eliminated from the observed data. The instrument drift is determined by making repeat observations on previously adjusted base stations at intervals not exceeding 2 hours. Scale readings at these base stations are plotted as a function of time and a drift curve is constructed. The proper drift correction for each field station is then interpolated from this curve.

The average error of closure for all base station loops before adjustment was ± 0.048 milligal. The largest error of closure for which adjustment was made was 0.18 milligal.

The force of gravity at any point varies with the distance of that point from the center of the earth. The elevation of the point of observation therefore has a definite influence on the observed value of gravity, other factors remaining constant. Geodesists divide the elevation correction into two parts when reducing gravity data. The first part, referred to in the literature as the "free air" correction, treats the observation station as though it were suspended in the air at a given elevation above sea level and assumes a theoretical decrease in gravity of 0.09408 milligal for each foot increase in elevation. The second part, generally termed the "Bouguer correction," provides for the additional downward pull of the layer of rocks between the station and sea level. This has been theoretically calculated as equal to an increase in gravity of 0.01278 milligal multiplied by the density of the rocks, for each foot of elevation above sea level.

For simplicity in computations, these two corrections are generally combined and, assuming a density of 2.0 for the Tertiary rocks forming the overburden in the bauxite region (value determined by density profiles),[10] the final elevation correction amounts to 0.0685 milligal decrease in gravity for each foot increase in elevation.

The purpose of this survey was to obtain information on the con-

[10] Nettleton, L. L. *Determination of Density for Reduction of Gravimeter Observations.* GEOPHYSICS, Vol. IV, No. 3, p. 176 (July 1939).

figuration of the bedrock, particularly the syenite, where it was covered by Tertiary sediments. It was therefore quite permissible to use the same elevation correction over the whole area. Differences in the gravity anomaly due to changes in density of the surface rocks, i.e., over Paleozoic or syenite outcrops, are eliminated with the regional anomaly correction. The great magnitude of the total anomaly and the low topographic relief of the area are such that any residual differences will have little or no effect on the interpretation of the local anomalies.

A total of six survey parties, three for each gravity meter, were required to run closed level lines between the various observation stations and first and second order bench marks previously established by the U.S.C. & G.S., U.S.G.S. and the Arkansas Geodetic Survey. In order to keep errors in elevation corrections below the observational accuracy of the instruments, it was necessary to determine the elevations of all stations with an accuracy of a few tenths of a foot.

When the error of closure of level loops was one foot or less, the loop was adjusted by dividing the error of closure proportionately between the stations; when the error of closure was greater than one foot, the loop was rerun.

No corrections for irregularities in terrain were applied. Calculations were made for a number of typical stations by Hammer's method[11] and the terrain effect was found to be generally less than 0.03 milligal. A very few stations observed on Fourche and Alexander mountains may have an uncorrected terrain effect of as much as 0.2 milligal.

The application of these various corrections to the observed readings automatically refers the geophysical data to an arbitrary geophysical datum and all variations in intensity are classed as anomalies indicative of changes in the configuration, structure or character of either the syenite or the Paleozoic bedrock.

PRESENTATION OF RESULTS OF GEOPHYSICAL SURVEYS

The duly corrected geophysical data may be prepared and presented for study and interpretation either in the form of plan maps or profiles. Both methods have certain advantages, and both have been used in this report.

In the preparation of geophysical maps the station sites and the corrected values for the observations are plotted on the map and con-

[11] Hammer, Sigmund. *Terrain Corrections for Gravimeter Stations*, GEOPHYSICS, Vol. 4, No. 3, p. 194. (July, 1939).

toured in the same manner as would be the case for a topographic map. Contour intervals are chosen commensurate with the accuracy of the data, the magnitude of the anomalies, and the scale used.

Fig. 3 shows the magnetic anomalies recorded in the central part of the area and includes the proved bauxite regions of both Pulaski and Saline Counties. The contour interval used is 100 gammas.

Fig. 4 shows the gravimetric anomalies observed in the same area and drawn with a contour interval of 5 gravity units* (0.5 milligal).

Fig. 5 shows the magnetic anomalies observed in the vicinity of the syenite mass near Magnet Cove, a short distance northwest of Malvern. Because of the great magnitude of the anomalies, the contours on this map were drawn, generally, with intervals of 1000 gammas. These intense anomalies are due to the presence of a relatively high percentage of magnetite in the rocks of this area.

Fig. 6 represents a subsurface contour map of the bedrock, adapted from a similar map prepared by the National Geophysical Company from data obtained during the course of a seismic survey made in September 1941 for the Reynolds Mining Corporation. The contour interval is 50 feet, and the contours represent the approximate configuration of the bedrock with no distinction between syenite, Paleozoic rock, and perhaps in a few instances, Midway limestone. Comparison of this seismic map with the subsurface map of Fig. 2, based on data obtained from drilling, indicates the relative accuracy of the method. Better results would have been obtained if more seismic depth determinations had been made at closer intervals, but even as presented it is evident that this method would be preferred, except as to cost, for contouring the syenite or Paleozoic surface when it is within a few hundred feet of the surface.

This map is included in this report through the courtesy of the officials of the Reynolds Mining Corporation and National Geophysical Company.

Fig. 7 represents magnetic and gravimetric observations taken along U. S. Highway 65 from Conway to Grady, and presented in the form of geophysical profiles.

Fig. 8 is a magnetic profile observed along U. S. Highway 67 from Arkadelphia to Benton, and Fig. 9 represents similar profiles observed along U. S. Highway 67 from Little Rock to Searcy and U. S. Highway 70 from Little Rock to Hazen.

* In gravity meter work it is customary, for convenience, to subdivide the milligal into 10 parts called "gravity units."

Fig. 10 represents a gravimetric profile observed along State Highway 30 from Little Rock to England, in Lonoke County.

Figs. 12 to 20 inclusive present additional data in the form of sketch maps and profiles and these figures are discussed at length in the chapter of this report dealing with the interpretation of the geophysical data.

GENERAL DISCUSSION OF GEOPHYSICAL RESULTS

In the discussion and interpretation of the geophysical data frequent reference will be made to the maps of Fig. 1, illustrating the general geology of central Arkansas, and Fig. 2, which presents subsurface geologic data obtained from drill holes. Reference to these maps and figures will be made by numbers, without mention of their titles.

Magnetic Results

The maximum disturbance of the earth's magnetic field was found to occur within the area covered by the magnetic map of Fig. 3. The Arkadelphia profile of Fig. 8 shows the gradual fading out of the magnetic disturbance to the southwest of Benton and, with the exception of the fringe of the Magnet Cove magnetic high observed near Malvern, an almost constant value for the corrected magnetic field in this area. This profile is representative of conditions observed in the entire area surveyed between the southwestern edge of the map of Fig. 3 and the town of Gurdon, a short distance southwest of Arkadelphia. As a consequence, we are justified in assuming that there are no buried igneous intrusions within the limits of the area surveyed southwest of Benton, with the exception of the Magnet Cove syenite mass whose existence was already known.

The Searcy and Hazen profiles of Fig. 9 show somewhat similar results. There are no magnetic anomalies on these profiles which can be correlated with the presence of buried igneous rocks. These profiles are representative of conditions observed northeast of the area covered by Fig. 3, with the exception of the area immediately adjacent to the northeastern edge of this map and east of the Arkansas River, where the northeastern fringe of the principal anomalous area of Fig. 3 gradually fades out.

The Geologic Map of Arkansas[12] shows a series of generally east-

[12] *Geologic Map of Arkansas.* Arkansas Geological Survey, Little Rock, Arkansas, 1929.

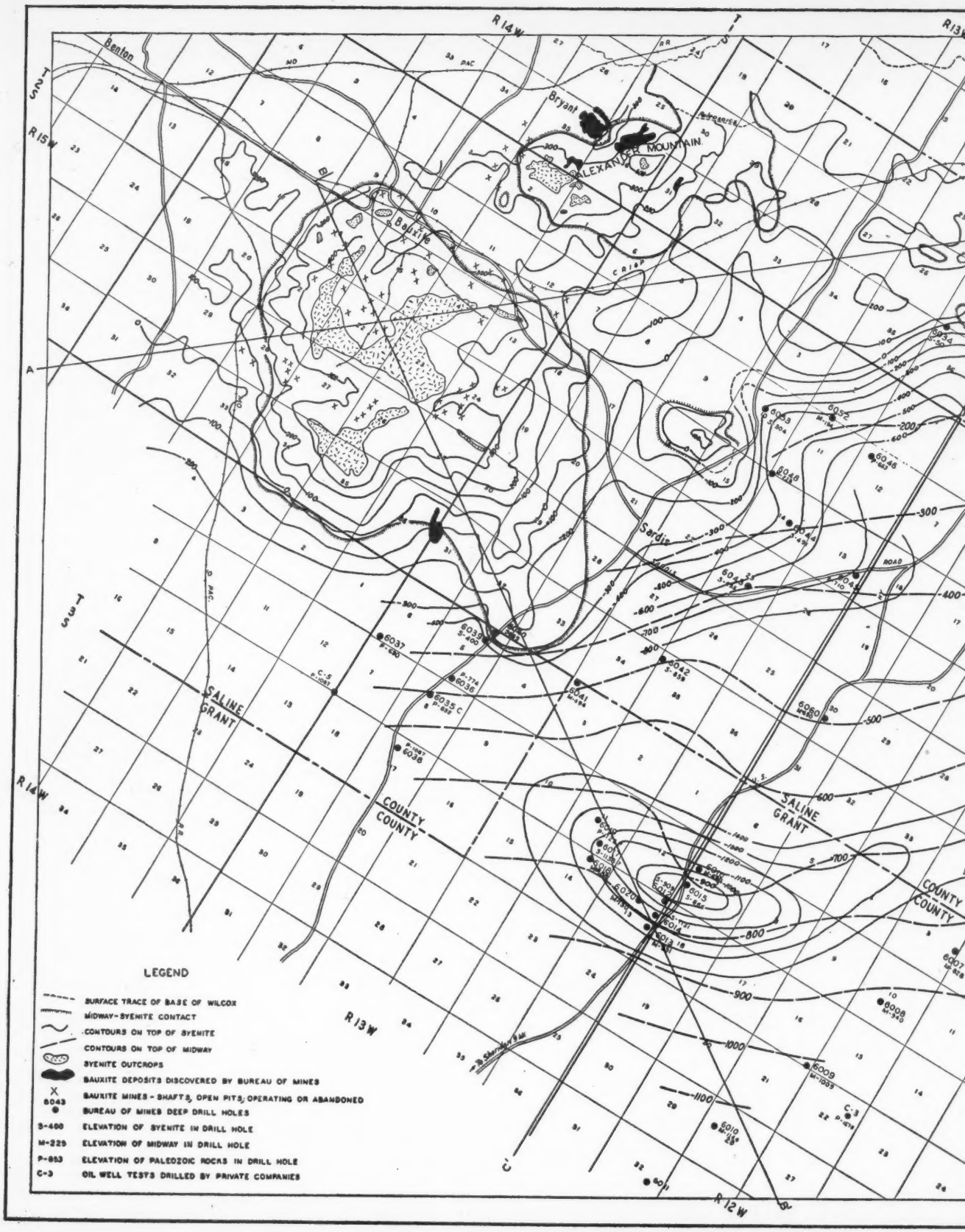
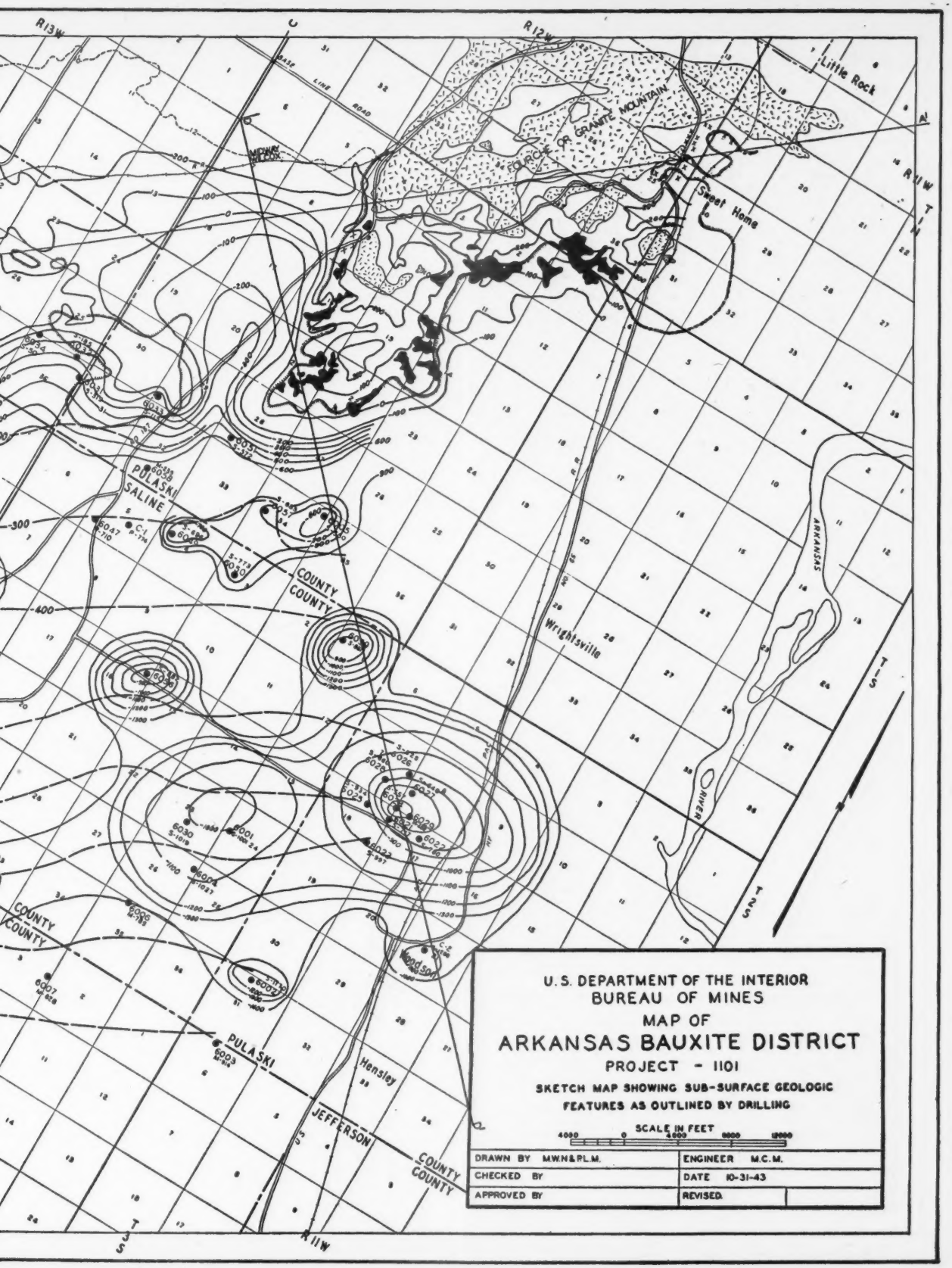


FIG. 2. Map of Arkansas Bauxite District showing subsurface geologic features as outlined by drilling. Midway-syenite contact h
black areas are bauxite deposits discover



ontact hatchured. Solid contours, top of syenite; dashed contours, top of Midway; contour intervals 100 feet. Irregular solid
discovered by Bureau of Mines.

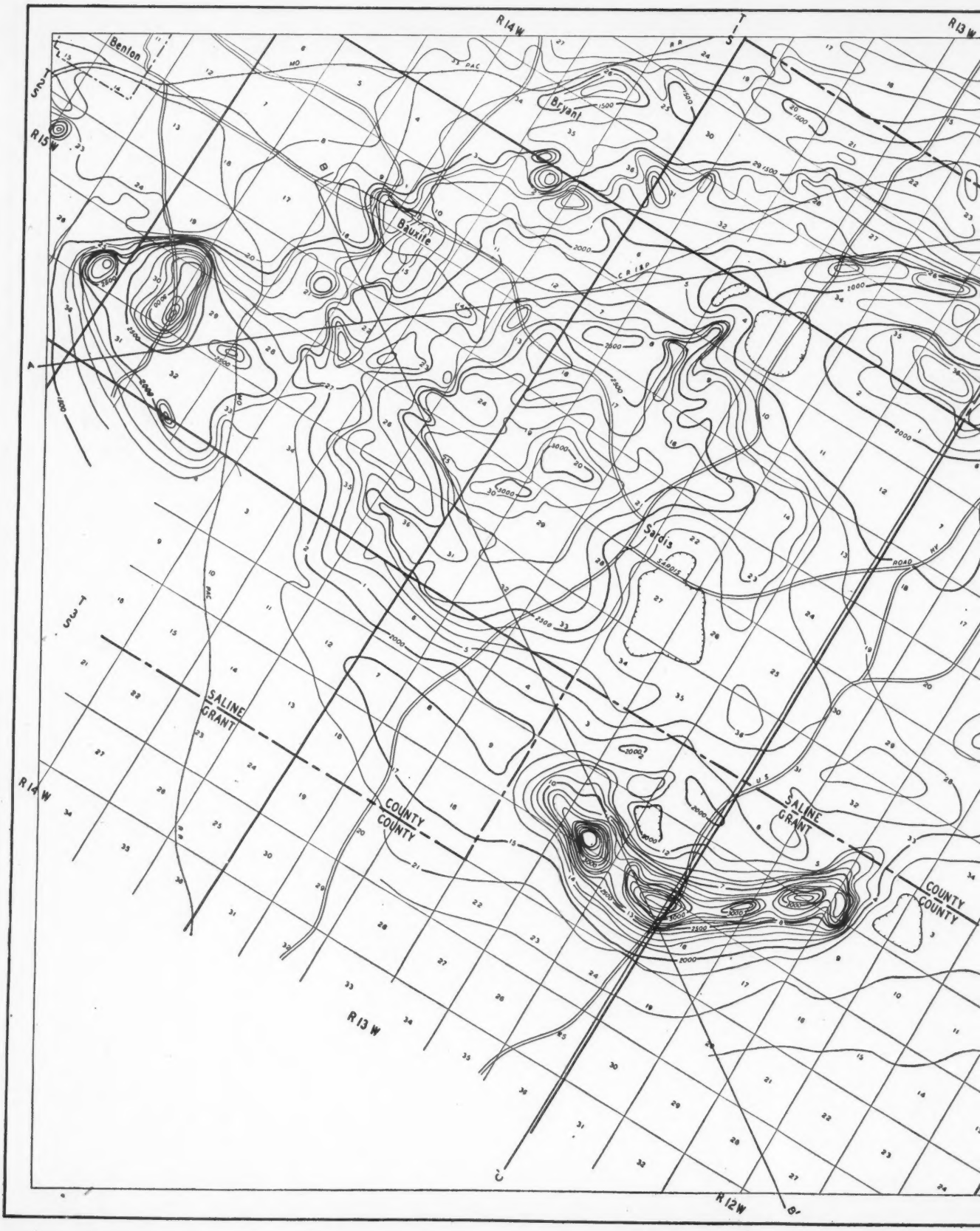
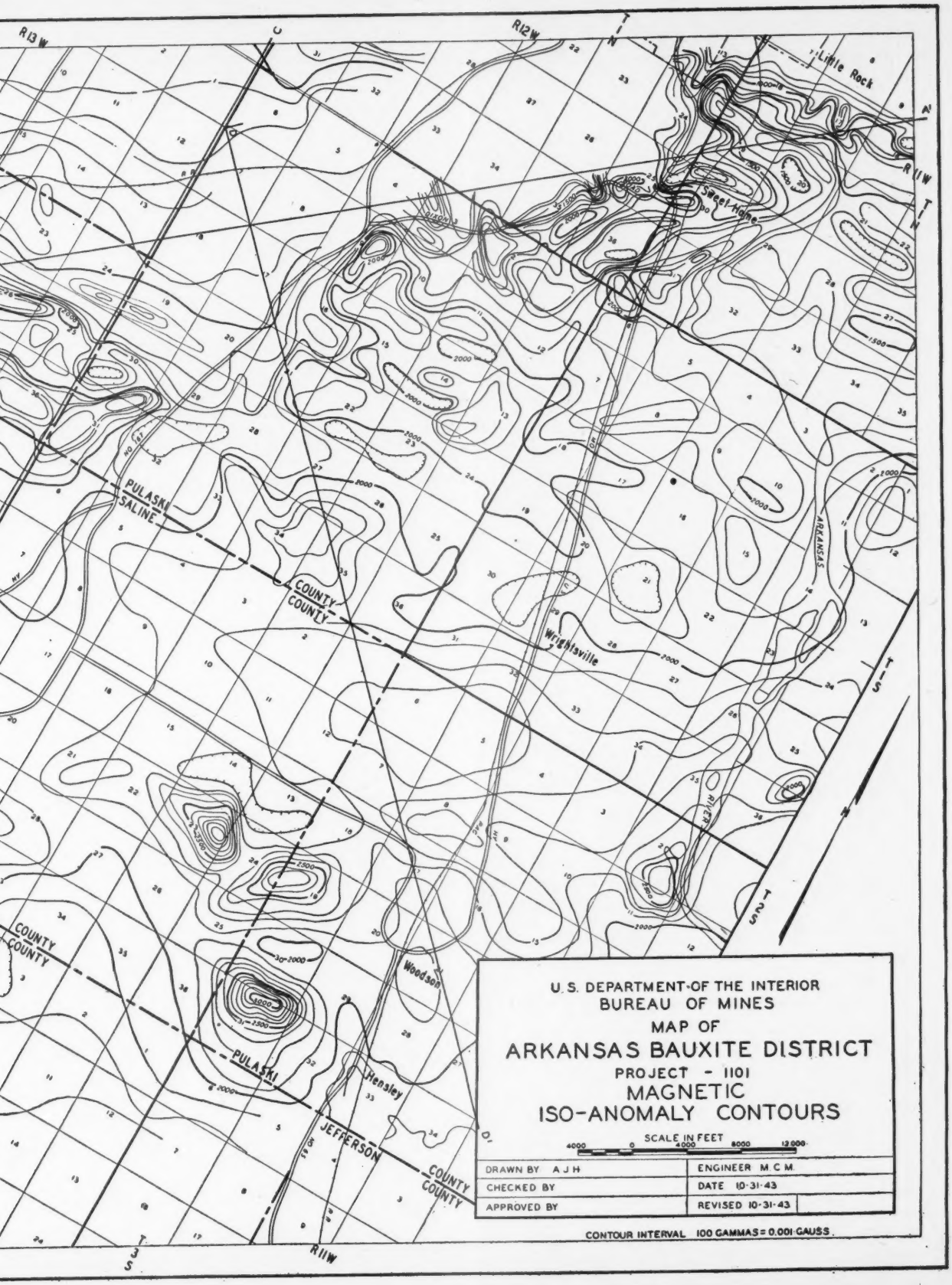


FIG. 3. Map of Arkansas Bauxite District showing magnetic iso-an



netic iso-anomaly contours. Contour interval 100 gammas.

ward-trending anticlinal folds in the Paleozoic rocks north of the Ouachita Mountain region, and it is possible that the broad anomaly centered about Cabot and Beebe, and the increase in intensity near Hazen may be due to uplifts in deep-seated more magnetic rocks related to these structures. There are not sufficient data to warrant any definite conclusions as to the true cause of the Cabot-Beebe and Carlisle-Hazen anomalies.

The Conway-Grady profile of Fig. 7 shows a broad, low-intensity anomaly at Conway which might also be related to the anticlinal folds shown on the Arkansas Geologic Map, but here again the data are inconclusive.

At Little Rock an area of low intensity indicates the effect of negative polarization on the northern flank of the syenite mass, and south of this is the principal anomaly due to the batholith proper. In the general vicinity of Pine Bluff, the magnetic intensity assumes an almost constant value.

From a study of the profiles of Figs. 7, 8 and 9 and other pertinent data, it is apparent that the normal corrected magnetic intensity for central Arkansas, as referred to the arbitrary datum selected, is approximately 1000 gammas. Areas showing corrected magnetic intensities greater than 1000 gammas therefore represent increases in magnetic intensity and are termed "positive" anomalies; areas showing intensities less than 1000 gammas represent less than normal intensity of the earth's magnetic field and are termed "negative" anomalies.

Considering all the above, the magnetic data represented on the map of Fig. 3 may be described as a single positive magnetic anomaly having a closure on the 1500-gamma contour almost within the limits of the map. Superimposed on this large anomaly are a number of localized highs and lows. These local features are of prime importance and will be discussed in greater detail in the following chapter on interpretation.

Gravimetric Results

The areas of maximum disturbance of the earth's gravimetric field are shown on the gravimetric map of Fig. 4. The Conway-Grady profile of Fig. 7 shows a rapid increase in gravity south of Conway nearly to Little Rock. This is most probably due to the approaching nearness of the core of the up-lifted area indicated on the sketch map of Fig. 1 as the Ouachita Mountain region and consisting of older, denser rocks. A pronounced decrease in gravity occurs in the vicinity

of the known occurrence of the syenite mass, changing again to a maximum about midway between Little Rock and Pine Bluff and then leveling off to a nearly constant value to either side of Pine Bluff.

The gravity profile from Little Rock to England (Fig. 10) does not show any pronounced anomalies of the order of magnitude of those shown on the map of Fig. 3 or on the profile of Fig. 7.

The gravimetric survey was not extended far enough beyond the limits of the disturbed areas to permit determination of the approximate value of the normal corrected intensity as referred to the arbitrary datum used. From the data available, it would appear that the normal value should be not more than 400 units as a maximum, and it is probably of the order of 200 units or perhaps even less. Profiles to Arkadelphia, Searcy, Camden, Fordyce and perhaps other points well out in the Coastal Plain area would be necessary to establish this point definitely.

The dominating feature of the gravity pattern shown on the map of Fig. 4 is a horseshoe-shaped ridge with a trough projecting northeastward from its open end. Superimposed upon these features is a large high south of Benton and Bauxite, rising from a spur trending northeast toward Alexander on the northern limb of the horseshoe. The Sheridan anomaly appears as a minor high on the southernmost tip of the plateau surrounding the southern limb of the horseshoe. There are numerous flexures in direction of the gravity contours and changes in gravity gradient which have the same general appearance as valleys, noses, and terraces on topographic maps. These minor features are of particular importance and will be treated in detail in the chapter on interpretations.

It will be noted that there is a definite similarity in the shape and position of the large magnetic high described in the preceding pages and the large gravity low mentioned in the paragraph above. Although the gravity trough, as represented on the map of Fig. 4, is open to the northeast, the Little Rock-England profile of Fig. 10 shows that this trough must close a short distance east of the river, as was the case for the large magnetic anomaly.

PRELIMINARY INTERPRETATION OF THE GEOPHYSICAL RESULTS

The purpose of the geophysical surveys was to locate hidden extensions of the known syenite masses and to discover any previously unknown syenite intrusions that might exist in the area and might fulfill the geological requirements for the occurrence of bauxite, that is, protrude above the top of the Midway clay.

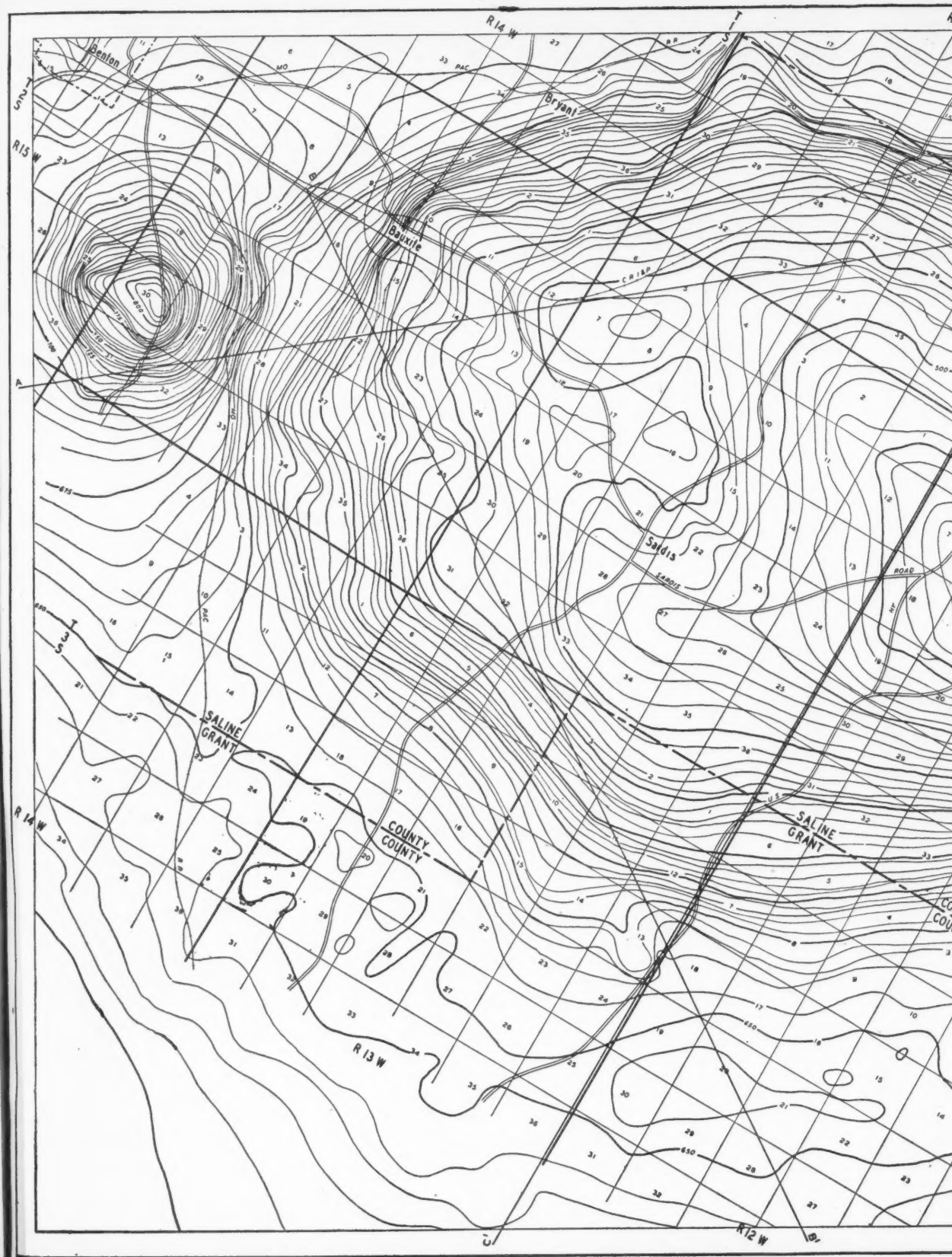
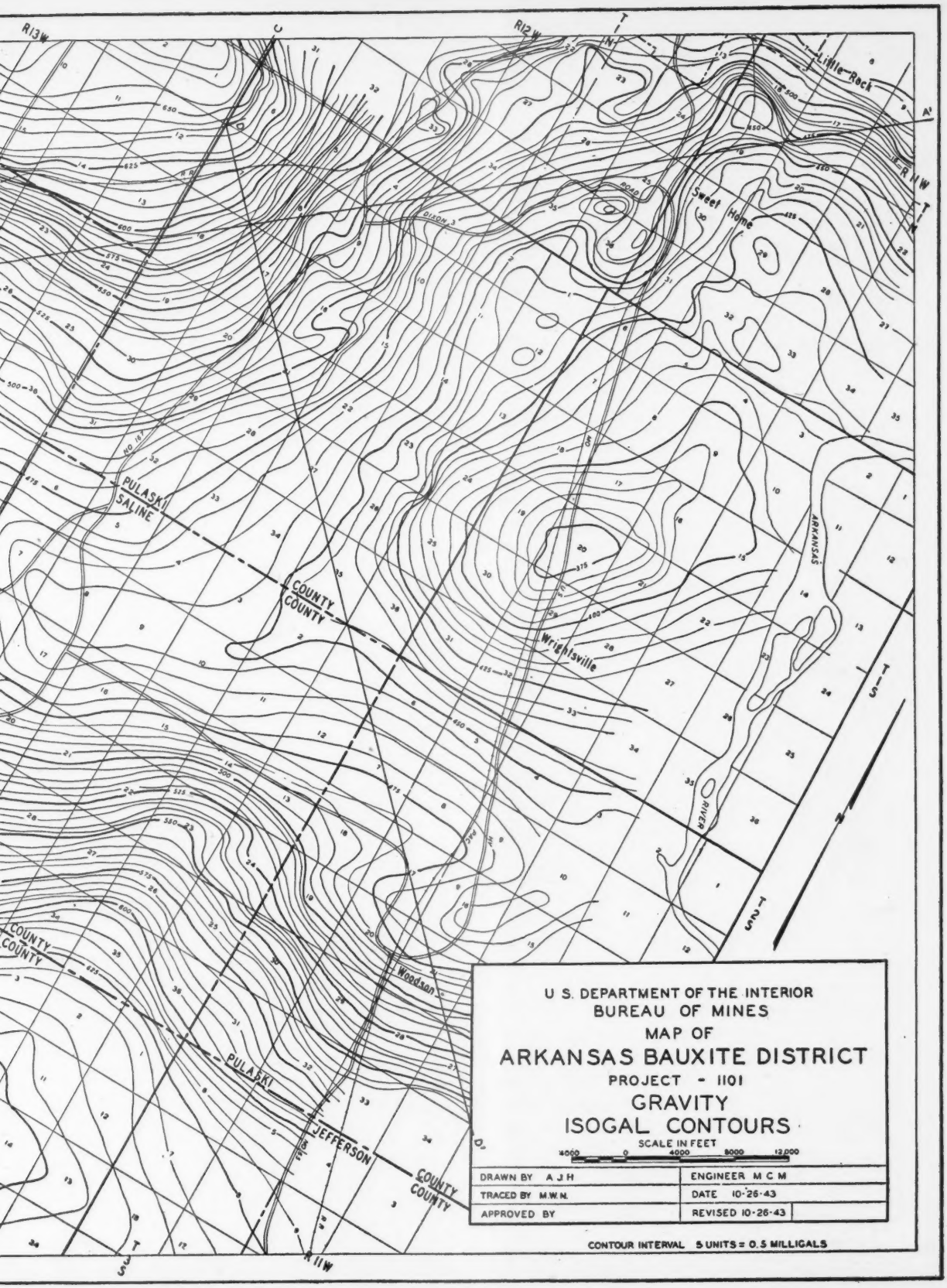


FIG. 4. Map of Arkansas Bauxite District showing gravity isoga



ogal contours. Contour interval is 5 gravity units (0.5 milligal.)

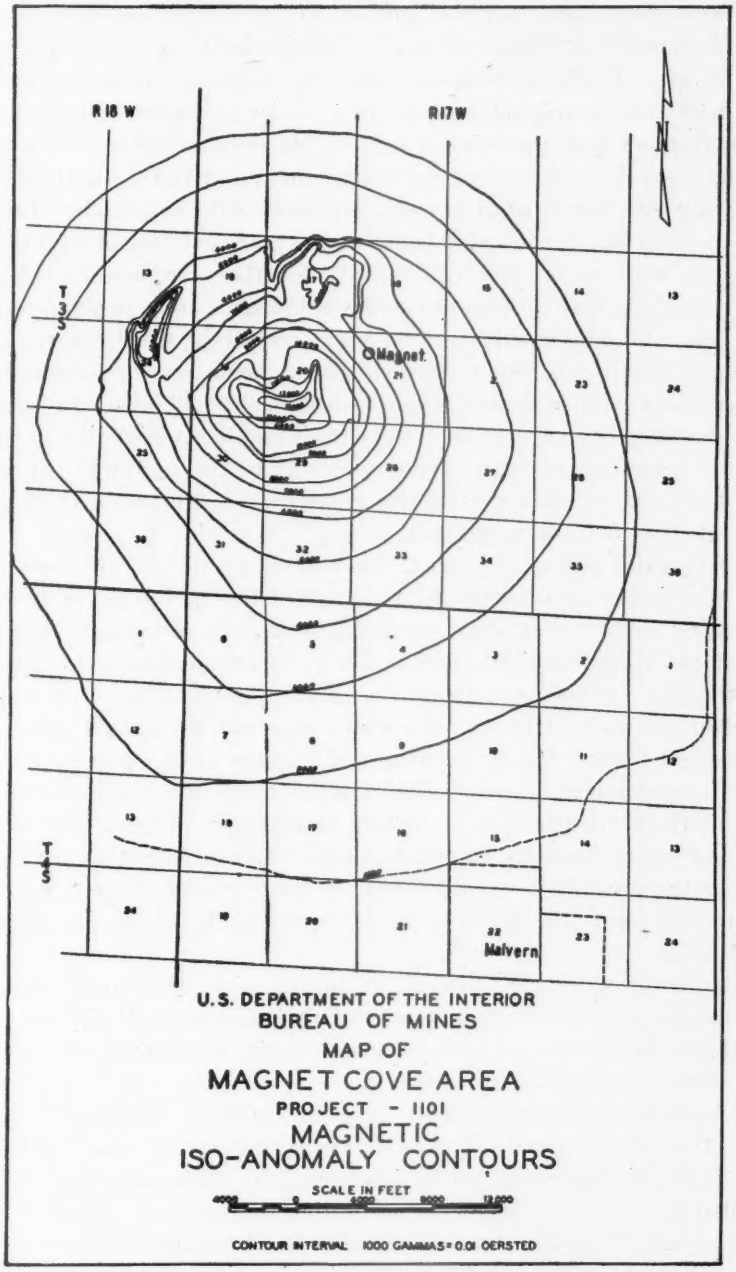


FIG. 5. Map of Magnet Cove area showing magnetic iso-anomaly contours. Contour interval is 1000 gammas.

Both geophysical methods applied are "potential" methods, and the instruments used measure relative changes in the vertical intensity of the natural force investigated. The gravimetric or magnetic effect of a unit mass or unit pole, respectively, varies inversely as the square of its distance from the point of observation and directly as the cosine of the vertical angle between the observation point and the unit mass. The intensity measured at any point represents the summation of the effects of all unit masses lying below and to all sides of the observation station. Small masses, located directly below the instrument and close to the surface, may produce anomalies of the same order of magnitude as those caused by much larger masses at greater depth. However, the anomaly due to the deeper mass will always be observed over a much greater area; and, in general, changes in intensity will be more regular and gradual. The greater the density or magnetic susceptibility of the mass causing the anomaly, the greater will be the magnitude of the anomaly, and, to a lesser extent, the greater will be the area over which the anomaly may be recognized.

The major part of the anomalies, both magnetic and gravimetric, recorded in the area covered by the maps of Figs. 3 and 4, are due to the presence of a very large mass of igneous rock of batholithic proportions. Minor localized highs and lows superimposed on the larger geophysical anomalies represent the effect of irregularities on the upper surface of the igneous mass which may well be termed cupolas, domes, or bosses, and/or petrographic changes in the igneous mass.

In considering the geophysical anomalies, the effect of the syenite batholith as a whole is of secondary or academic interest. The local anomalies are, however, of primary importance because they may indicate the presence of syenite domes or bosses which, if they project above the top of the Midway, might be favorable for the occurrence of bauxite.

To better study the form and magnitude of the local anomalies, it is necessary to eliminate that part of the total anomaly due to the batholith as a whole, or to the Paleozoic rocks, and referred to as the "regional" anomaly.

Admitting the large dimensions of the batholith and the principal structural features of the Paleozoic formations, it was assumed that the regional geophysical anomalies caused by them would be represented by smooth sweeping curves on the contour maps as well as on the profiles. These curves were drawn in by inspection and the results of drilling have proved the qualitative interpretation of the local

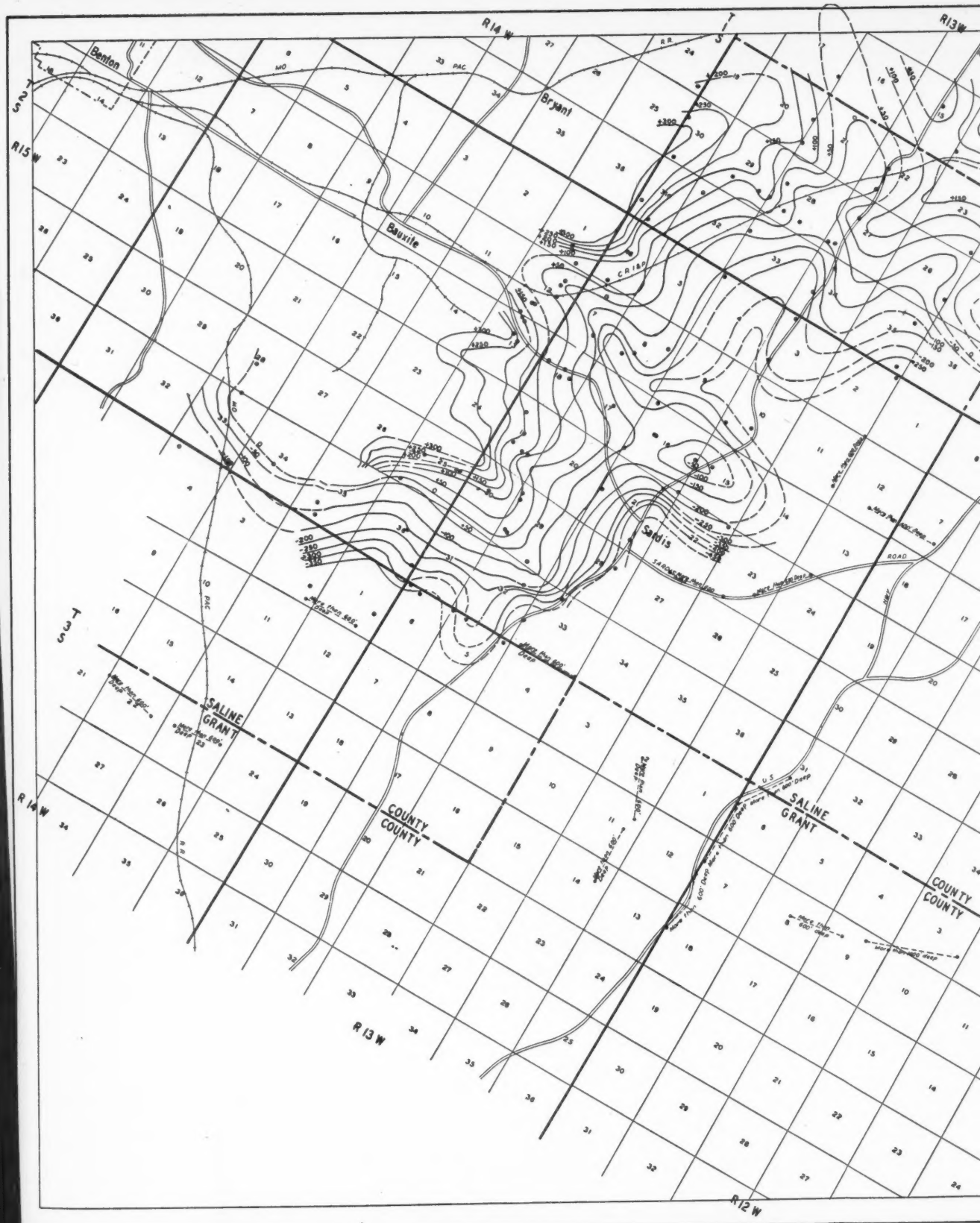
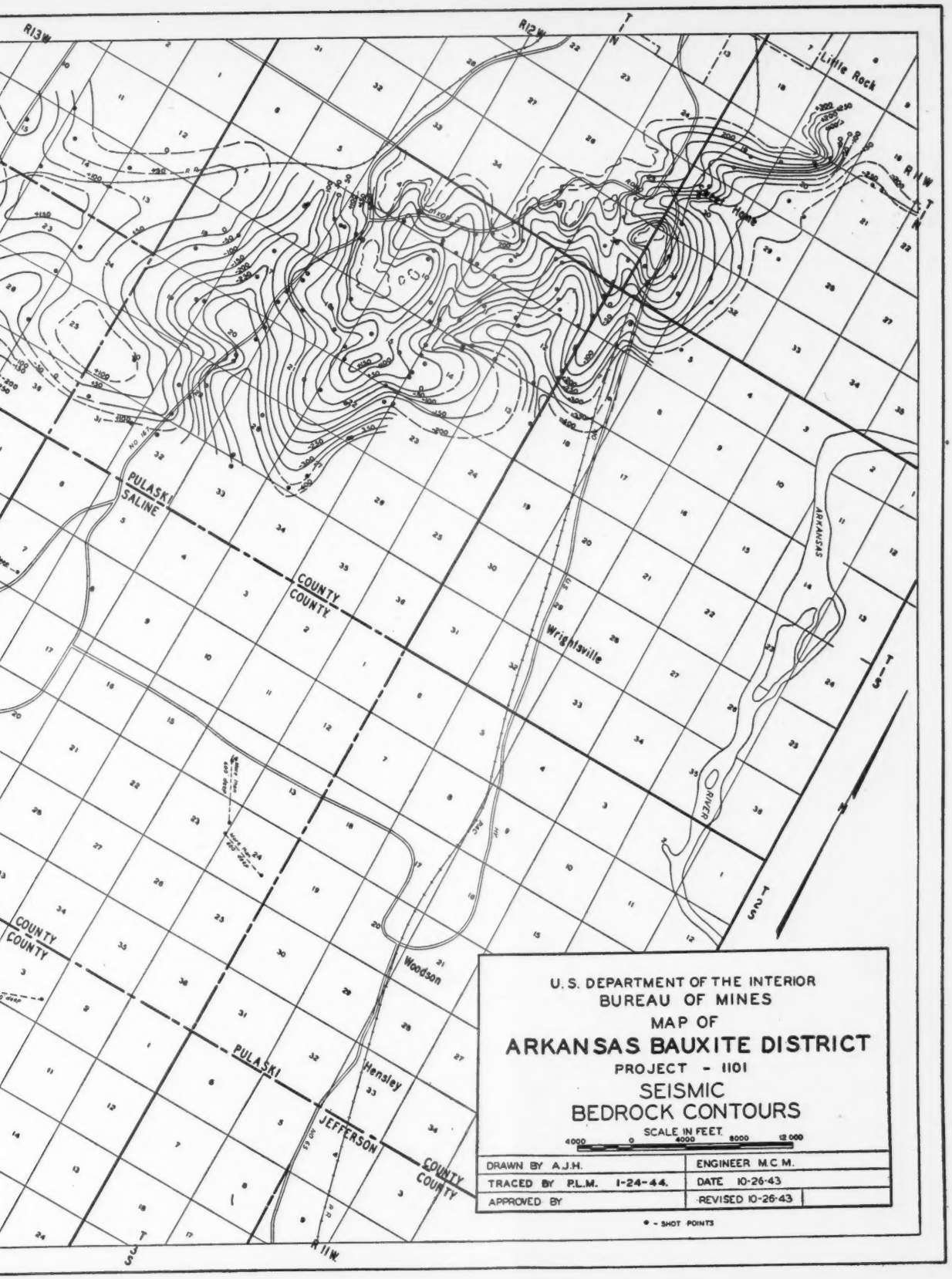


FIG. 6. Map of Arkansas Bauxite District showing refract
are shown by solid circles. Contou



ng refraction seismic bedrock contours. Shot-points
s. Contour interval is 50 feet.

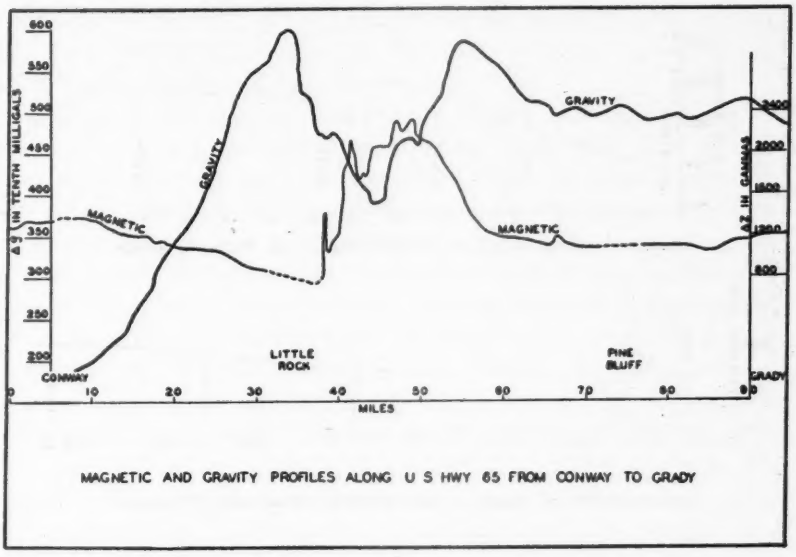


FIG. 7. Magnetic and gravity profiles along U. S. Highway 65 from Conway to Grady.

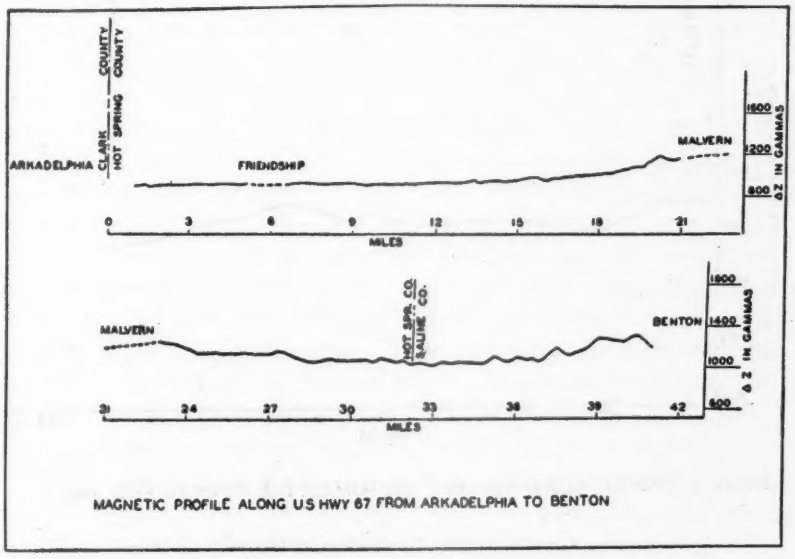


FIG. 8. Magnetic profile along U. S. Highway 67 from Arkadelphia to Benton.

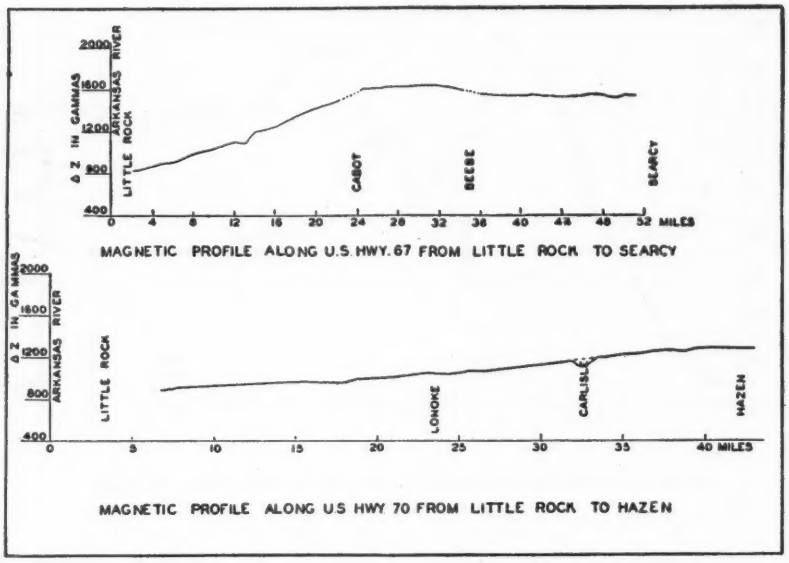


FIG. 9. Magnetic profiles along U. S. Highways 67 and 70.

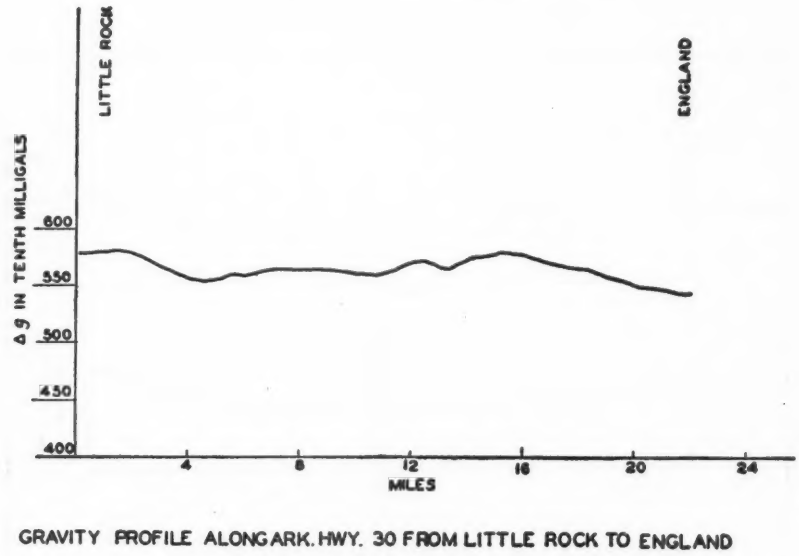


FIG. 10. Gravity profile along Arkansas Highway 30 from Little Rock to England.

anomalies to be sufficiently accurate for the purpose of the survey.

The procedure followed in the determination of the regional anomaly is illustrated in Figs. 11, 13 and 15.

Fig. 11 shows magnetic and gravity profiles crossing two igneous intrusions whose presence has been proved by drilling. The regional anomaly has been drawn as a smooth and regular curve eliminating the jagged peaks on the observed anomalies. The residual or local anomalies, obtained by subtracting the regional curves from the observed curves, are also shown. It should be noted that, whereas the observed magnetic anomalies over the syenite (trachyte) and peridotite plugs had approximately the same amplitude, the residual or local anomaly over the peridotite plug is more intense even though the top of the plug is considerably deeper. This is to be expected, as peridotite has a much greater magnetic susceptibility than syenite or trachyte. Although peridotite is somewhat denser than syenite or trachyte, the slightly greater gravity anomaly over the deeper peridotite mass probably is due to its greater relative vertical thickness. The syenite mass indicated in this figure is believed to be a cupola or boss on the syenite batholith whose effect has been removed with elimination of the regional anomaly, while the peridotite plug is doubtless an isolated intrusion, only connected with the igneous basement at great depth.

In Figs. 13 and 15 the observed gravity anomalies have been shown by contours, and the dotted lines represent the idealized contours of the regional anomaly. The differences between the regional and observed anomalies at various points were determined and coutoured to indicate the approximate position of domes or bosses on the syenite batholith. Comparison of these sketches with the subsurface map of Fig. 2 will show the agreement between the geophysical interpretation and the presence of syenite domes proved by the drill.

Figs. 12 and 14 give the magnetic anomalies over the same areas for which the gravity anomalies were shown in Figs. 13 and 15. These have not been corrected for regional anomaly because the local anomalies were so intense as to make elimination of the regional effect of secondary importance. It is of interest to note that, comparing the magnetic map of Fig. 12 with the subsurface map of Fig. 2, the maximum magnetic anomaly falls some distance south of the syenite dome proved by the drill. Similarly, the more pronounced magnetic anomalies shown in Fig. 14 do not correspond with the highest dome of syenite indicated in the same area of the map of Fig. 2.

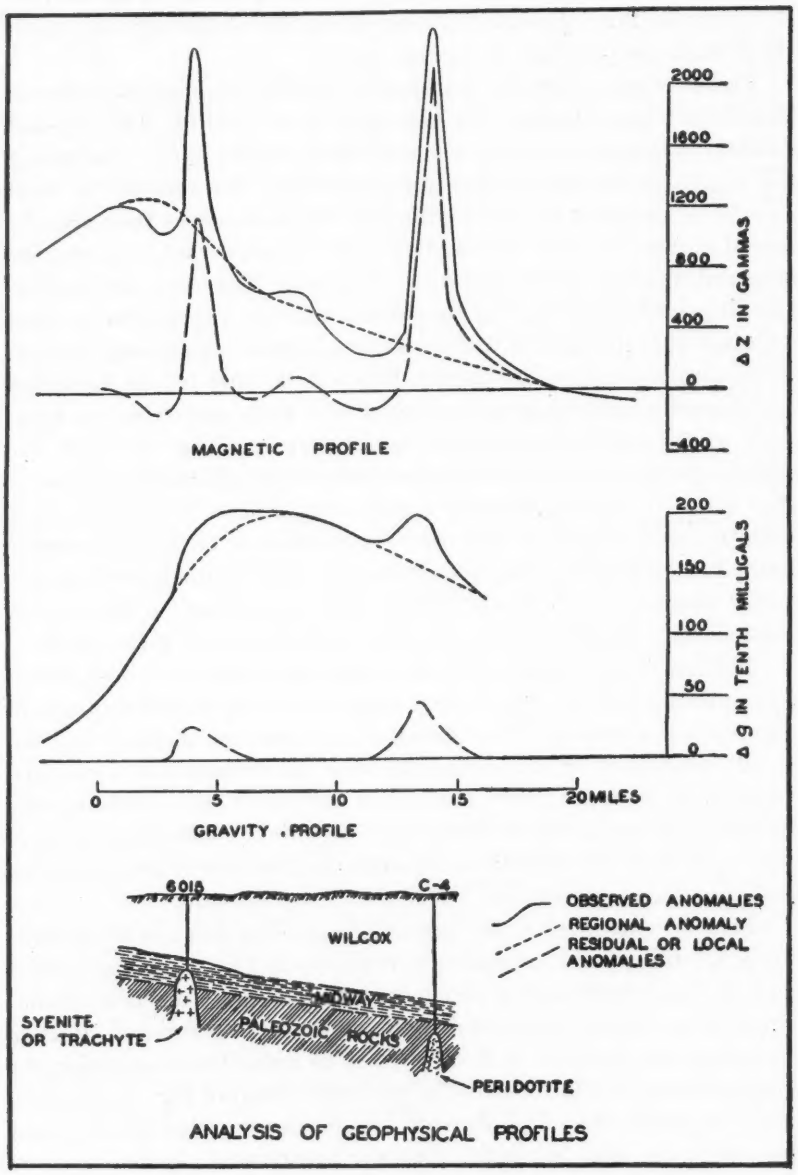


FIG. 11. Illustrating removal of regional effects from geophysical profiles.

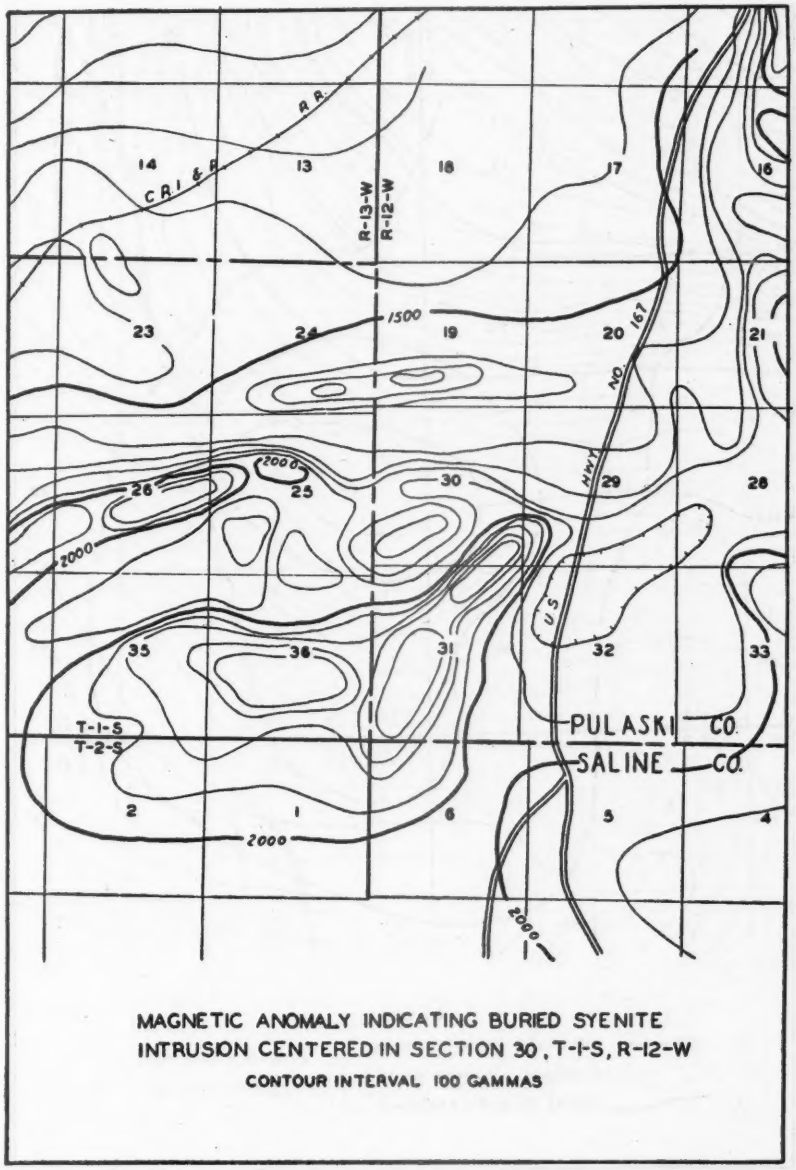


FIG. 12. Magnetic anomaly indicating dome on syenite batholith. (See map of Fig. 2, Sec. 30, T. 1 S., R. 12 W.) Contour interval 100 gammas.

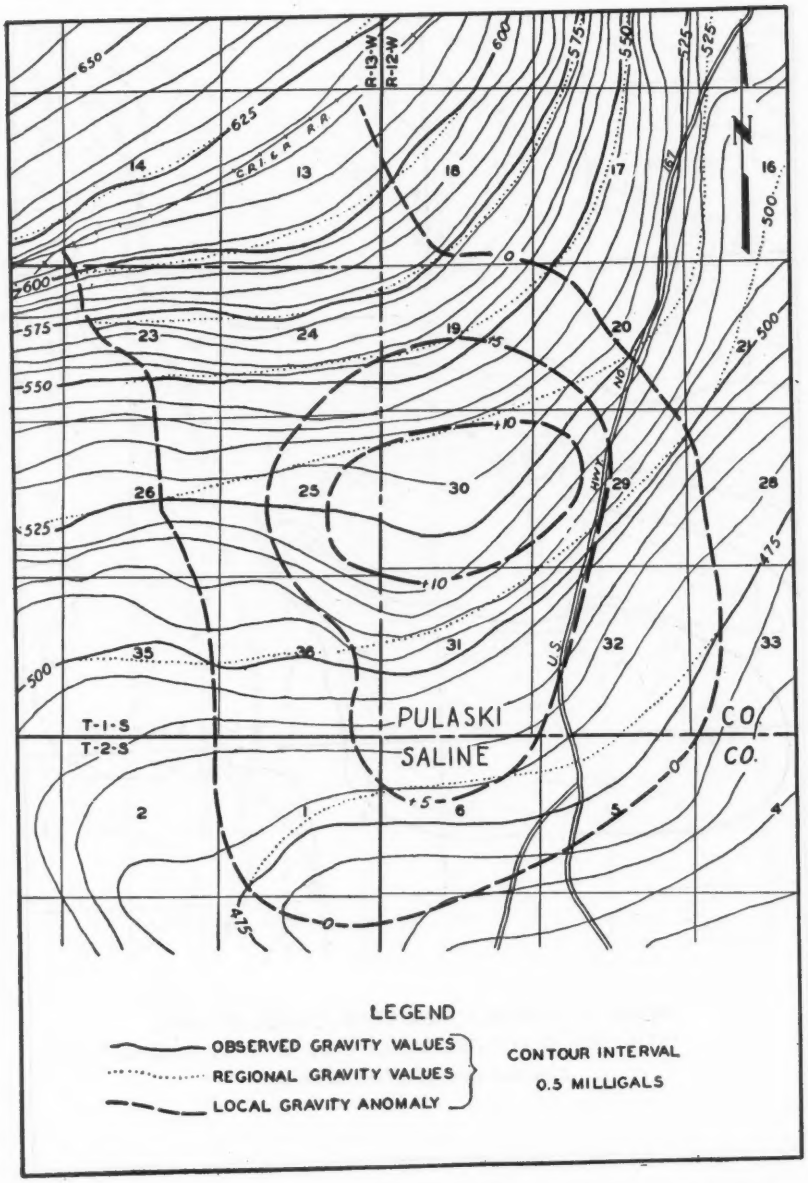


FIG. 13. Analysis of gravity anomaly indicating dome on syenite batholith, showing observed gravity by solid contours, regional gravity by dotted contours, and residual gravity by heavy dashed contours. Contour interval is 5 gravity units. (See map of Fig. 2, Sec. 30, T. 1 S., R. 12 W.)

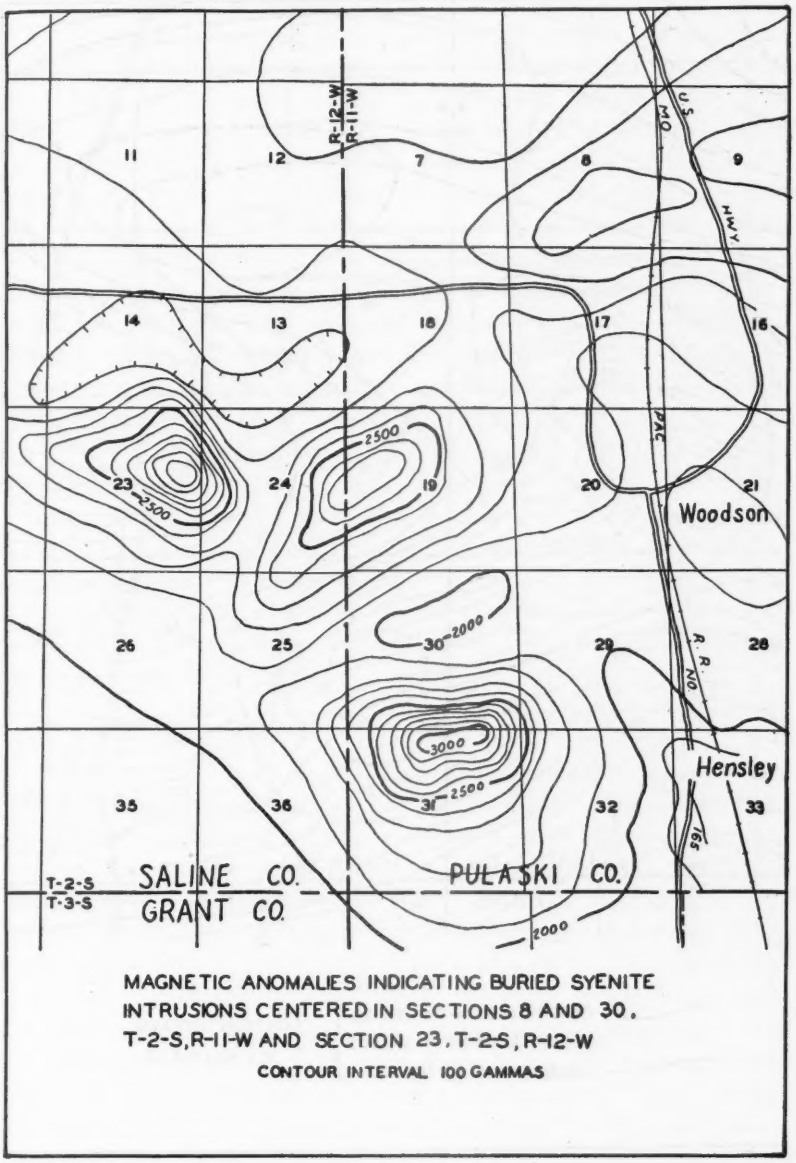


FIG. 14. Magnetic anomalies indicating domes on syenite batholith. (See map of Fig. 2, T. 2 S., R. 11 and 12 W.) Contour interval 100 gammas.

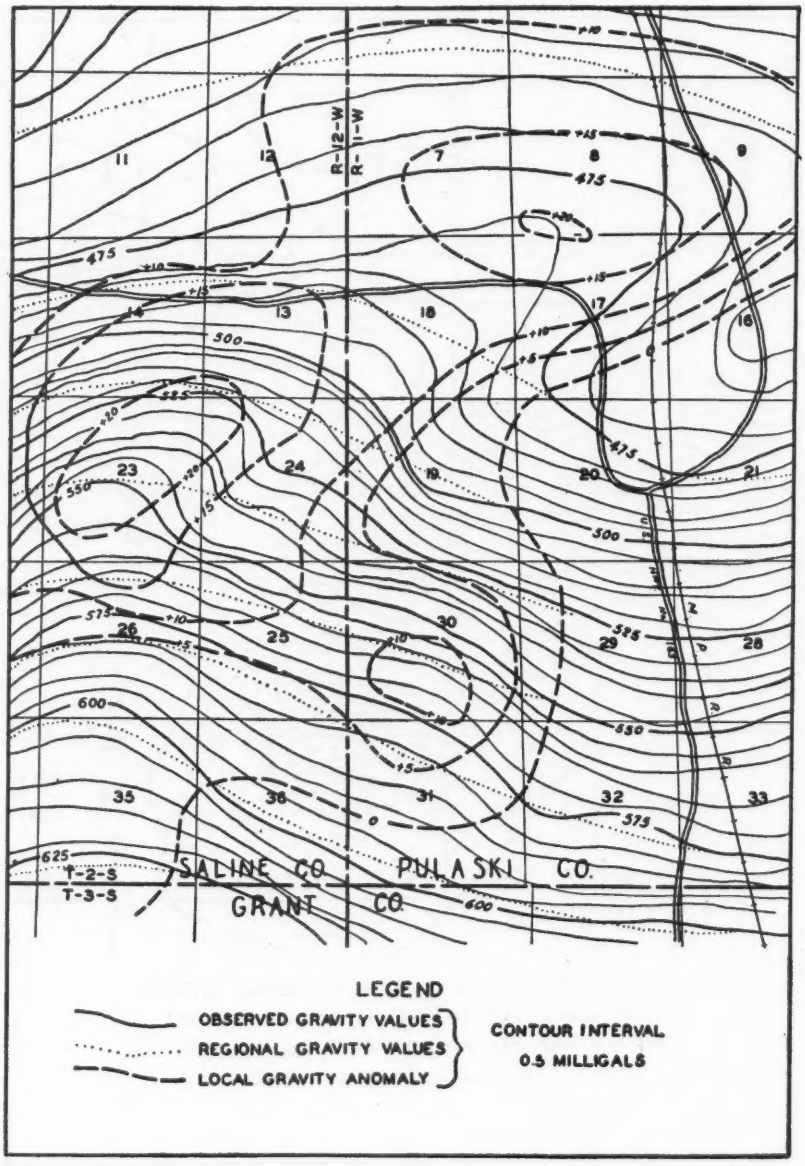


FIG. 15. Analysis of gravity anomalies indicating domes on syenite batholith, showing observed gravity by solid contours, regional gravity by dotted contours, and residual gravity by heavy dashed contours. Contour interval is 5 gravity units. (See map of Fig. 2, T. 2 S., R. 11 and 12 W.)

The explanation of this lies in the phenomenon of magnetic polarization. The earth's magnetic field in central Arkansas is inclined at an angle of 66°, the dip being to the north. When the magnetic lines of force approach a mass of rock of high magnetic susceptibility, they change their direction slightly to follow the path of least resistance and pass through this rock. A positive magnetic pole is induced on the upper part of the southern flank of the rock mass, and a negative magnetic pole appears on the lower part of the northern flank. If the rock mass is sufficiently close to the surface, magnetic intensity along its northern edge decreases, and this appears as a magnetic low which, under certain conditions, may develop into a definite "negative" anomaly. This phenomenon is quite evident over the syenite outcrop called Fourche or Granite Mountain, between Little Rock and Sweet Home, and is also evident in the "local anomalies" of Fig. 11. It was not so evident on this profile until the regional anomaly had been eliminated.

Space does not permit discussion of all of the local anomalies that have been analyzed. As a matter of fact, familiarity with the geophysical maps and the area makes it quite simple to visualize the approximate location of local anomalies indicative of the possible presence of domes without the necessity of actually eliminating the regional anomaly from the observed data.

RESULTS OF DRILLING ON GEOPHYSICAL ANOMALIES

A Sullivan Type 41 drill, capable of drilling to depths greater than 2000 feet, was contracted for to permit investigating the geophysical anomalies interpreted as indicating the presence of hitherto unknown syenite masses, and the maximum depth to which drilling would be carried was arbitrarily set at 1500 feet.

In all, 60 holes were drilled with this rig. The locations of these holes, numbered from 6001 to 6060, are shown on the subsurface map of Fig. 2. The elevations of the top of the rocks in which the holes were bottomed are also shown on this map. Table I summarizes pertinent data obtained from the logs of these holes. The average depth for the 60 holes drilled was 1057.7 feet, and the total footage drilled with this large rig was 63,463.7 feet. Holes 6054 and 6055 were abandoned before reaching the Midway because of technical difficulties. If they are eliminated from the calculations, the average depth of the remaining 58 holes is increased to 1089.6 feet.

From a study of Table I and the logs of the individual holes, it is

TABLE I. U. S. BUREAU OF MINES DEEP DRILL HOLES—SULLIVAN #41 RIG

D.H. No.	Collar Elev.	Total Depth	Midway Depth	Midway Elev.	Igneous Rock Depth	Igneous Rock Elev.	
6001	293.8	1295.0	922	−628	1295	−1001	Fine-grained syenite.
6002	279.8	1452.5	1084	−804	1450	−1170	Ultra basic igneous rock.
6003	289.4	1500.0	1203	−914			Midway—black shale.
6004	255.7	1283.3	982	−726	1283	−1027	Syenite.
6005	272.6	855.0	518	−245	853	−580	Syenite.
6006A	325.9	1500.0	1115	−789			Midway—black shale.
6007	352.1	1500.0	1180	−828			Midway—shale.
6008	340.2	1500.0	1280	−940			Midway—shale.
6009	325.0	1500.0	1334	−1009			Midway—black shale.
6010	305.9	1500.0	1450	−1144			Black, silty Midway.
6011	317.0	1500.0					Wilcox—sand.
6012A	341.3	1253.5	1070	−729	1250	−909	Blue gray syenite.
6013	319.1	1500.0	1150	−831			Midway—black shaly clay.
6014	314.6	1446.4	1110	−795	1446	−1131	Blue gray syenite.
6015	331.8	1199.0	1032	−700	1198	−866	Trachyte.
6016A	343.8	1201.0	1034	−690			Midway limestone.
6017	281.5	1426.5	1057	−775	1420	−1138	Basic igneous rock.
6018	282.8	1083.0	1071	−788			Midway—black silty clay.
6019	285.2	1409.0	1041	−756	1407	−1122	Alt. metavol. & novac. Paleoz.
6020	318.6	1286.0	1069	−750			Midway—limestone
6021	257.0	976.5	855	−598	974	−717	Syenite boulders & syenite.
6022	230.1	1012.0	835	−605	1010	−780	Syenite. (boulders?)
6023	252.5	1251.5	972	−720	1250	−997	Syenite.
6024	249.0	806.0	730	−481	806	−557	Vy. hd. basement rock. Paleoz.
6025	258.2	1192.2	864	−606	1192	−934	Vy. hd. basement rock. Paleoz.
6026	254.7	1082.2	775	−520	1080	−825	Syenite.
6027	228.9	879.5	746	−517	878	−649	Syenite?
6028	255.6	1118.2	775	−519	1116	−860	Syenite?
6029	252.3	796.0	734	−482			Midway lime with syenite.
6030	292.2	1312.6	924	−632	1311	−1019	Syenite.
6031	341.7	662.6	510	−168	661	−319	Syenite or trachyte.
6032	333.0	518.1	434	−101	518	−185	Syenite. No core.
6033	310.6	426.9	404	−93	426	−115	Syenite.
6034	386.2	436.5	384	2	436	−50	Syenite.
6035C	345.2	1177.7	869	−524	1177	−832	Vy. hd. rock. Paleoz. No core.
6036	326.2	1101.5	785	−459	1100	−774	Gray quartzite—Paleozoic.
6037	354.0	1044.0	739	−385	1043	−690	Novaculite—Paleozoic.
6038	347.1	1425.0	1002	−655	1404	−1057	Fissile shale—Paleozoic.
6039	313.6	714.0	667	−353	713	−400	Fresh gray "granite"—syenite.
6040	343.4	602.7			602	−259	Gray, "granite" syenite.
6041	289.9	1045.0	784	−494			Midway limestone.
6042	303.1	1164.9	805	−502	1162	−859	Syenite.
6043	342.3	977.0	747	−405	977	−635	Syenite.
6044	367.3	858.0	651	−284	858	−491	Syenite.
6045	338.3	1053.0	730	−392	1048	−710	Syenite.
6046	383.0	1042.0	641	−258	1036	−653	Conglomerate. Paleozoic.
6047	328.2	1042.0	635	−307	1038	−710	Novaculite. Paleozoic.
6048A	415.2	866.0	640	−225			Midway limestone.
6049	305.3	1002.0	615	−310	1001	−696	Syenite.
6050	273.8	1048.0	630	−356	1047	−773	Syenite.
6051	348.1	921.4	598	−250	920	−572	Syenite.
6052	373.1	800.0	567	−194			Midway limestone.
6053	399.9	707.0	530	−130	704	−304	Syenite.
6054	299.0	143.0					Wilcox—sand and gravel.
6055	260.2	125.0					Wilcox.
6056	278.1	1162.0	760	−482	1160	−882	Syenite.
6057	242.4	927.0	552	−310	925	−683	Syenite.
6058A	290.1	823.0	529	−239			Midway. Circulation lost.
6059	261.9	1121.5	700	−438	1120	−858	Syenite Cuttings. No core.
6060	271.6	910.0	761	−490			Midway. Circulation lost.

found that 30 holes were bottomed in syenite, 2 in basic igneous rock, and 1 in trachyte, making a total of 33 bottomed in igneous rocks. Of the remainder, 9 were bottomed in Paleozoic rocks, probably representing roof pendants on syenite, 15 in the Midway formation and 3 (including the 2 that were abandoned) in the Wilcox formation.

Of the 15 holes bottomed in the Midway, 6 were abandoned because the maximum depth of 1500 feet had been reached, 6 were bottomed in hard limestone, and 3 were abandoned because of lost circulation. Of the holes abandoned in the Wilcox, one was drilled the maximum contracted depth of 1500 feet without reaching the Midway, and the other two were abandoned at shallow depths because of caving and lost circulation.

Table II gives pertinent data relative to four abandoned oil wells. The locations of three of these drill holes are indicated on the sub-

TABLE II. DATA FROM OIL WELLS DRILLED IN DISTRICT[13]

D.H. No.	*Coll. Elev.*	*Total Depth*	*Midway Depth*	*Midway Elev.*	*Paleozoic Depth*	*Paleozoic Elev.*	*Ign. Depth*	*Rock Elev.*	*Owner*
C-1	256	3410			1030	−774			Wayman O. & G. Co. Fee #1 Well
C-2	259	1547				−1300?	1547	−1288	Wonder State Dev. Co. Wilson #1 Well
C-3	342	2064			2020	−1678			Cambrian Trust Co. Fee #4 Well
C-4	281	2286	1634	−1353	2096	−1815	2284	−2003	Shaffer O. & R. Co. Youngblood #1 Well

surface map of Fig. 2, the fourth on the sketch map of Fig. 16, and their data were taken under consideration in the preparation of this report. It will be noted that two of these holes were reported as bottomed in igneous rock while the other two bottomed in Paleozoic rocks.

During the period May 1, 1942, to December 31, 1943, the Bureau of Mines drilled 2766 holes, aggregating 660,821 feet, in this district. These holes were drilled primarily on the basis of geology and a very large proportion of the total represents holes drilled to block out the bauxite deposits discovered and indicated on the subsurface map of Fig. 2. However, the geophysical data presented on the maps of Figs. 3 and 4 confirmed the areas drilled as favorable and, if no geological data had been available, the drilling could have been conducted on the basis of the geophysical data with essentially the same results.

[13] Spooner, W. C., *Oil and Gas Geology of the Gulf Coastal Plain in Arkansas*. Parke-Harper Printing Company, Little Rock, Arkansas, 1935.

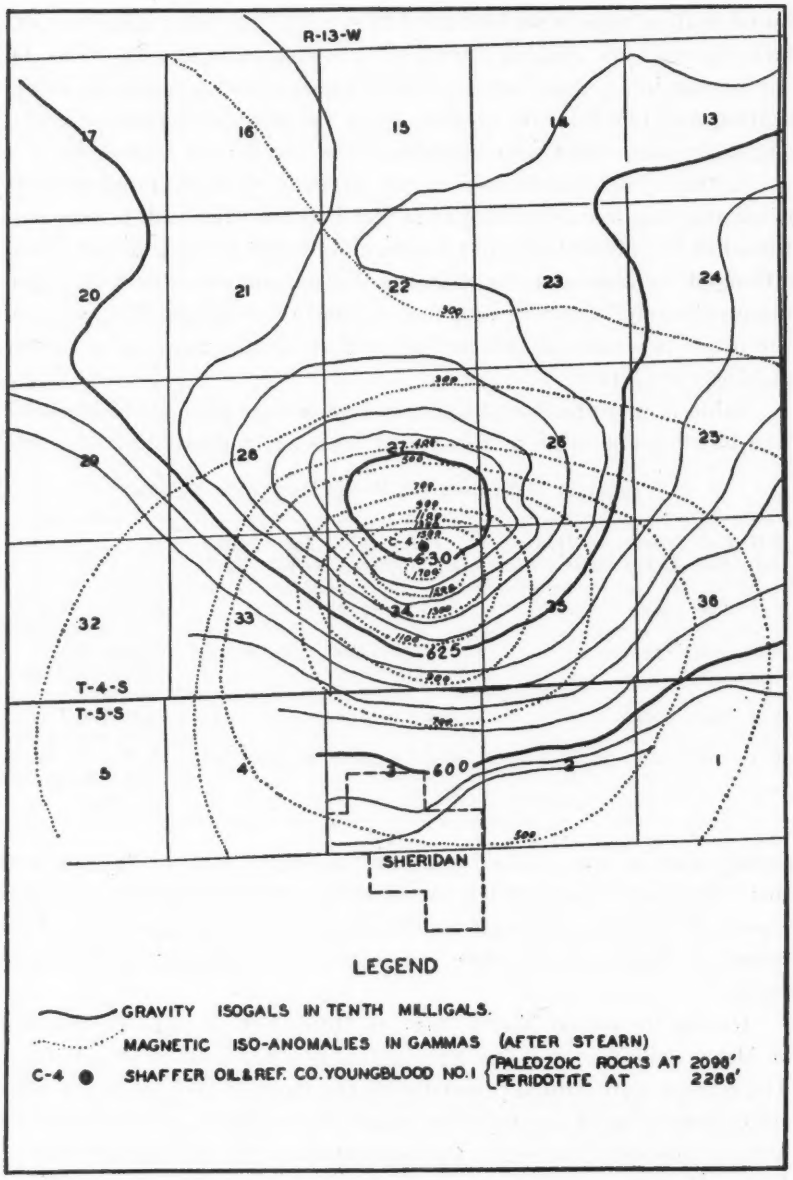


FIG. 16. Geophysical anomalies over peridotite plug near Sheridan, Ark. Solid lines are gravity contours at 5 gravity unit contour interval, dotted lines are magnetic contours (after Stearn) at 200 gamma contour interval.

The logs of these holes, as well as a mass of subsurface data obtained through the courtesy of the bauxite mining companies operating in the district, were utilized in the preparation of the subsurface map of Fig. 2, particularly in the areas surrounding and between the syenite outcrops.

Geologists of the Federal Geological Survey, under the direction of R. P. Bryson and Mackenzie Gordon, logged the overburden, identified the position of the bauxite-kaolin zone, and cooperated in the description of the cores. They also aided in the preparation of the subsurface map, particularly in the proved bauxite areas surrounding the syenite outcrops.

FINAL INTERPRETATION OF GEOPHYSICAL DATA

A general discussion of the results of the geophysical surveys made in this region is contained in War Minerals Report 202.[1] The procedure used in the preliminary interpretation of the geophysical data and the theories on which it was based are described in an earlier chapter of this report. Logs of holes drilled since the completion of the geophysical surveys have furnished data for a more accurate subsurface control and bottom hole cores from many of the deep drill holes furnished specimens for the determination of some of the physical properties of the basement rocks. A combination of all this information permits a final interpretation which shows a very close correlation between the results of the two geophysical surveys and the drilling.

The densities and magnetic susceptibilities for numerous specimens of rocks of the region are tabulated in Table III. Some of these values were taken from Heiland's[14] report and are so indicated.

The number of specimens available was too small to permit determination of the most accurate mean values of density and magnetic susceptibility, but they were sufficient to give the range of variation to be expected and approximate mean values of the two physical properties that affected the geophysical observations.

A study of the data given in Table III brings out several facts that have an important bearing on the interpretation of the geophysical anomalies and which are summarized below:

[14] Heiland Research Corporation. *Magnetic Survey of the Bauxite Region of Central Arkansas. Magnetic Survey of the Magnet Cove Region, Arkansas. Gravity Survey of the Bauxite Area, Arkansas.* Reports to the U. S. Bureau of Mines, December, 1942, January, 1943 and May, 1943 (Inedit).

TABLE III. *Geophysical Properties of Rocks of District*

Rock	*Locality*	*Density*	*Magnetic Susceptibility*
*Bauxite		2.02	118×10^{-6} **
Bauxite		2.54	
Bauxite		2.22	
*Gray granite (syenite)	Granite Mt.	2.51	1004×10^{-6}
*Rotten granite (syenite)	Granite Mt.	2.46	1338×10^{-6}
*Blue granite (syenite)	Fourche Mt.	2.63	2056×10^{-6}
Syenite. slightly weathered	D.H. 6022	2.34	
Syenite	D.H. 6022	2.48	
Syenite (boulder)	D.H. 6021	2.53	
Syenite	D.H. 6026	2.52	
Syenite	D.H. 6034	2.59	
Syenite	D.H. 6043	2.48	
Syenite	D.H. 6045	2.58	
Syenite	D.H. 6051	2.56	
Syenite	D.H. 6056	2.58	
Syenite	D.H. 6040	2.52	
Syenite	D.H. 6039	2.70	
Syenite	D.H. 6049	2.61	
Syenite	D.H. 6030	2.62	
Syenite	D.H. 6033	2.61	
Syenite	D.H. 6046	2.32	
Syenite	D.H. 6050	2.43	
Syenite	D.H. 6053	2.54	
Syenite	D.H. 6057	2.53	
Syenite? (contact rock)	D.H. 6028	2.53	
Syenite or trachyte	D.H. 6031	2.39	
*Basic igneous rock	Granite Mt.	3.06	8514×10^{-6}
Ultra basic igneous rock	D.H. 6002	3.10	
Basic igneous rock	D.H. 6017	2.83	
*Paleozoic rock	Douglasville	2.61	0
Paleozoic rock gray quartzite	D.H. 6036	2.66	
Paleozoic rock novaculite	D.H. 6037	2.69	
Paleozoic rock novaculite	D.H. 6047	2.48	
Paleozoic rock fissile shale	D.H. 6038	2.44	
Paleozoic rock altered metavolcanic & novaculite	D.H. 6019	2.73	
*Tertiary	From density profiles	2.0	Probably near 0
Limestone—Midway	D.H. 6041	2.47	
Limestone—Midway	D.H. 6048	2.66	
Clay —Midway		2.05	

* Data from Heiland's Report. Method of determining not specified.

** Recently, cores of high iron bauxite have been recovered which apparently contain magnetite and are strongly magnetic. Their susceptibility has not been determined.

TABLE III—*Continued*

SUMMARY

Rock		*Range of Densities*		
		Minimum	*Maximum*	*Average*
Bauxite	3 Samples	2.02	2.54	2.23
Syenite	23 Samples	2.32	2.70	2.52
Basic igneous rock	3 Samples	2.83	3.10	3.00
Paleozoic rocks	6 Samples	2.44	2.73	2.60
Midway Limestone	2 Samples	2.47	2.66	2.56
Tertiary clays and sands				2.0

Facts Relating to Magnetic Survey

1. The Tertiary and Quaternary rocks forming the overburden are apparently inert from the magnetic standpoint.
2. The near-surface Paleozoic rocks are also magnetically inert.
3. The syenites (granites) have a moderate magnetic susceptibility which varies according to the type of syenite.
4. The more basic igneous rocks have a very high magnetic susceptibility which is entirely normal for this type of rock.

Facts Relating to Gravimetric Survey

1. The mean density of the Tertiary rocks that form the overburden, as determined by density profiles, is 2.0. The Quaternary river sands may have a density as low as 1.8, whereas the measured density of specimens of the thin beds of Midway limestone averages 2.56.
2. The density of specimens of bauxite varied from 2.02 to 2.54, with a mean value of 2.23 for 3 samples.
3. The density of the syenites varied from 2.32 to 2.70 with an average of 2.52 for 23 specimens.
4. The density of the Paleozoic rocks varied from 2.44 to 2.73 with a mean value of 2.60 for 6 specimens.
5. The density of the basic igneous rocks varied from 2.83 to 3.10 with an average of 3.00 for 3 samples.

A comparison of the magnetic profiles of Figs. 8 and 9 indicates the possibility of a small regional magnetic anomaly due to deep-seated rocks in the lower or pre-Paleozoic basement. It is of the order of only 200 or 300 gammas and is entirely inconsequential within the area covered by the magnetic map of Fig. 3, and can be ignored in the interpretation of the magnetic data. Before entering into a theoretical

interpretation of the geophysical results, it is of interest to consider the correlation between the recorded geophysical data and geological information obtained as a result of drilling on the geophysical anomalies. This correlation is presented graphically in Figs. 16–20, inclusive, and described in the following paragraphs.

Fig. 16: This figure presents the gravimetric anomaly observed over the Sheridan peridotite plug, and, for comparison, Stearn's[8] magnetic anomaly over the same feature. The Bureau of Mines magnetic survey did not extend this far south. The location of the Schaffer Oil and Refining Company oil well on this anomaly (probably drilled before Stearn's survey and on the basis of other geophysical data) is shown on the sketch map. This dry hole encountered what was reported to be "peridotite" at a depth of 2286 feet. The location of this test is within the area of the maximum gravity and magnetic anomalies, although their respective centers are separated by almost 1500 feet. Remembering that polarization effects tend to throw the maximum positive magnetic anomaly to the south, whereas the gravity maximum should be directly above the center of the intrusive mass, it seems probable that the center of this igneous plug should be a little farther north and perhaps a little closer to the surface than this single hole indicates.

Nevertheless, this is an excellent example of the geophysical anomalies recorded over an isolated igneous plug, and it must be kept in mind that a more-detailed survey by both geophysical methods might have indicated a much closer correlation.

Fig. 17: This represents a northeast-southwest profile which crosses the southern end of the Bauxite (Saline County) and the Granite (Fourche) Mountain (Pulaski County) syenite outcrops. The location of this profile is shown as Section A–A′ on the maps of Figs. 2, 3 and 4.

The high-intensity magnetic and gravimetric anomalies indicated at the 16-mile point on this profile can only be interpreted as due to the presence of a mass of basic igneous rock of high magnetic susceptibility and high density. The broad anomalies recorded by both methods indicate that it must occur at considerable depth, and it is not incongruous to admit that it was not reached by Bramlette's drill hole shown on the section. As indicated on the figure, its crest is probably much deeper than the 500 odd feet shown on the geologic section. The circular form of the magnetic and gravimetric anomalies shown on the maps of Figs. 3 and 4 indicate that this igneous mass occurs

in the form of a circular plug similar to and comparable with the Sheridan plug whose geophysical effects were demonstrated in Fig. 16. In all probability, it is entirely unrelated to the syenite batholith which is the major igneous intrusion of the region.

East of this basic intrusive, and over the exposed syenite outcrop, the magnetic intensity varies abruptly, showing the effect of polarization, and the gravitational intensity falls, showing the effect of the lesser density of the syenite as compared to the surrounding Paleozoic

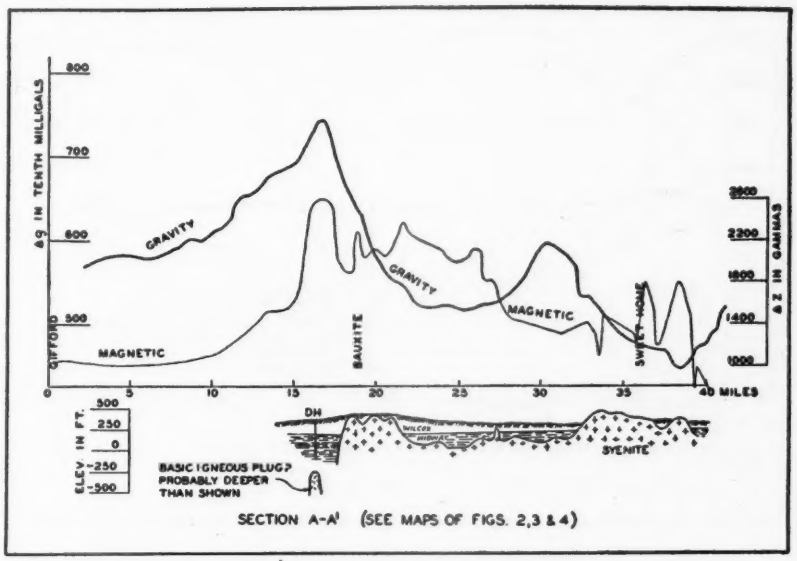


FIG. 17. Magnetic and gravity profiles, and geologic section based on subsurface data, along Section A–A′ of Figs. 2–4.

rocks. Proceeding northeastward, the magnetic intensity decreases as we approach the northern boundary of the syenite mass, which is negatively polarized, as a whole, but shows intense local polarization due to the irregular configuration and near surface proximity of the syenite rock.

The local gravity high at the 30-mile point is due, in part, to the ridge of syenite which protrudes above the Midway as shown on the gravity map of Fig. 4 and on the sketch map of Fig. 13. It is also probable that shallow beds of Midway limestone occurring above the syenite in this locality are reflected in this local gravity high.

The effect of the lower mean density of the syenite as compared to the Paleozoic rocks is quite evident over the syenite outcrop centered around the 35-mile point of the profile.

Fig. 18: This represents magnetic and gravimetric profiles along the line of geologic Section B–B′ indicated on the maps of Figs. 2, 3 and 4. The effect of the high magnetic susceptibility of the syenite is quite evident on the magnetic profile, even that due to the secondary

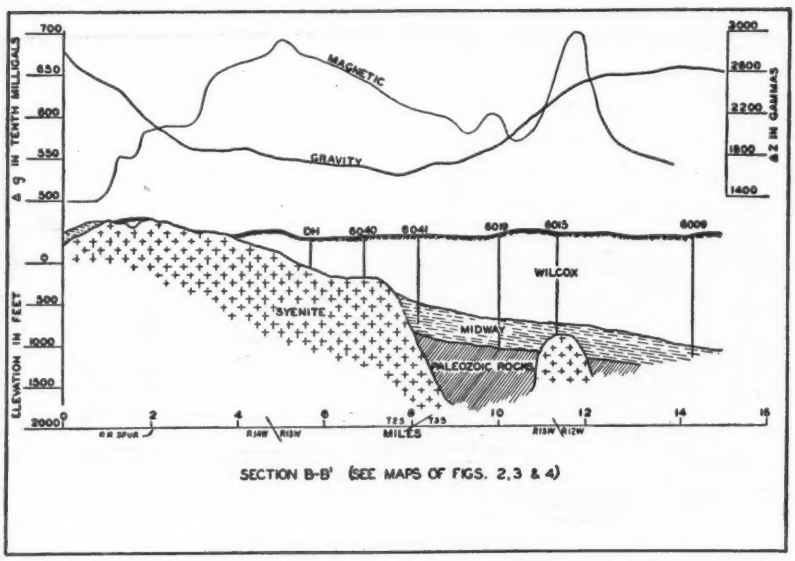


FIG. 18. Magnetic and gravity profiles, and geologic section based on subsurface data, along Section B–B′ of Figs. 2–4.

dome or boss at the 11.5-mile point. The gravity profile shows the effect of the lesser density of the syenite, as compared to that of the Paleozoic rocks, but there is no definite indication of the secondary dome, which shows up so clearly on the magnetic profile and which was checked by drill hole 6015. This apparent inconsistency is due to the angle at which the profile crosses this igneous mass because its effect on the gravity pattern is quite clearly shown on the gravity map of Fig. 4. The apparent local magnetic anomaly indicated at the 10-mile point on this profile probably represents a ridge on the flank of this intrusive below the top of the Paleozoic rocks and hence was not reached by the drill.

Fig. 19: This represents data recorded along Section C–C′, shown on the maps of Figs. 2, 3 and 4 (range line between 12 W and 13 W). The syenite high at the 5-mile point rises above the Midway, as indicated on the map of Fig. 2. It is near the northern edge of the syenite batholith and the magnetic data show that it is negatively polarized. It protrudes into the low-density Tertiary rocks and therefore gives rise to a local positive gravity anomaly. The magnetic profile remains

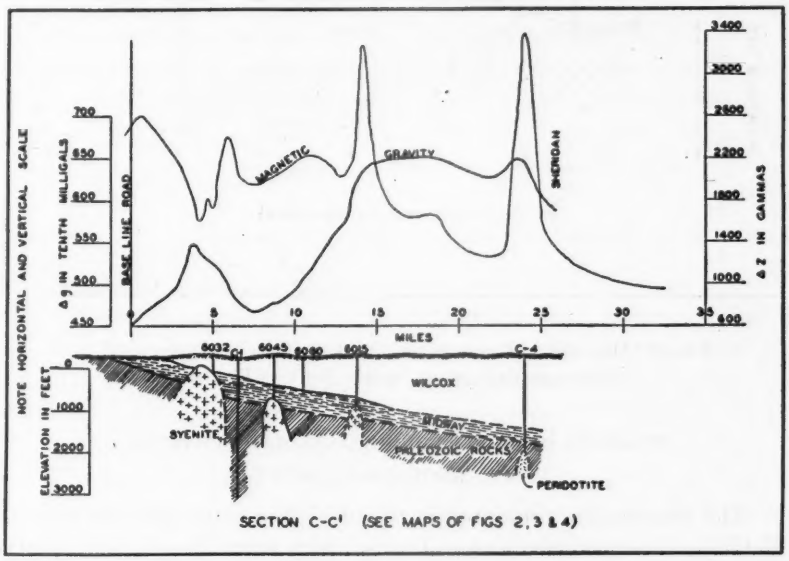


FIG. 19. Magnetic and gravity profiles and geologic section based on subsurface data, along Section C–C′ of Figs. 2–4.

high and the gravity profile low from the beginning of the section to the 12-mile point, indicating the high magnetic and low-density character of the syenite batholith as a whole. Beyond the 12-mile point the denser Ouachita Mountain Paleozoic rocks give rise to a broad gravity high. The local anomalies near Sheridan represent the effects of the peridotite plug already presented in Figs. 11 and 16.

Fig. 20: This figure represents profiles along Section D–D′ of the maps of Figs. 2, 3 and 4, and confirms the results of the other profiles discussed in the preceding paragraphs. Here also the syenite batholith shows up as positive magnetic and negative gravity anomalies while the superimposed domes or bosses are indicated as positive local magnetic and gravity anomalies.

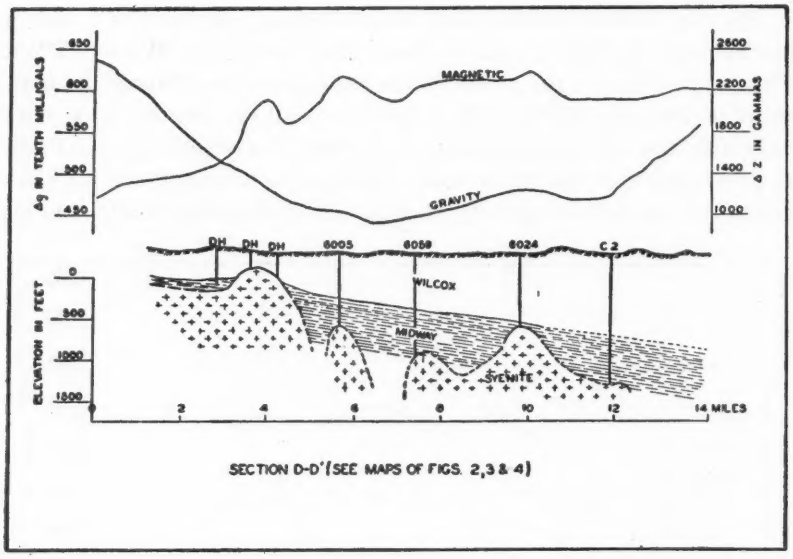


FIG. 20. Magnetic and gravity profiles, and geologic section based on subsurface data, along Section D–D′ of Figs. 2–4.

SUMMARY OF FACTS DEDUCED FROM GEOPHYSICAL AND GEOLOGICAL DATA

The information presented in the preceding pages permits the formulation of certain fundamental facts which enter into the interpretation of the geophysical data. These facts may be tabulated as follows:

1. The magnetic anomalies recorded in the area are due almost entirely to the presence of igneous rocks.
2. The regional magnetic anomaly reflects a small increase in the magnetic intensity from southwest to northeast, probably due to deep-seated lower or pre-Paleozoic rocks. Added to this is the large anomaly best-illustrated in Fig. 7 from the 35- to 55-mile points on the profile. This anomaly is due to an igneous intrusion of batholithic proportions.
3. Superimposed on the combined regional anomalies is a series of local anomalies due to domes or bosses on the batholith.
4. The northern edge of the batholith is negatively polarized, and evidence of similar polarization is found on most of the local magnetic anomalies.

5. The gravity anomalies recorded in the area are due to the combined effects of igneous intrusions and Paleozoic rocks buried beneath the Tertiary overburden.
6. The regional gravity anomaly is composed of two components of opposite sign: A. A large positive anomaly due to the denser Paleozoic rocks of the Ouachita Mountain region indicated on the sketch map of Fig. 1. B. A large negative anomaly due to the lighter syenite batholith which was intruded into the denser Paleozoic formations. This feature is also best illustrated in Fig. 7.
7. Superimposed upon the combined regional anomalies is a series of positive local anomalies due to domes or bosses on the batholith.
8. The syenite outcrops in Pulaski and Saline Counties are on the northern edge of the batholith.

CORRELATION OF GEOPHYSICAL DATA WITH PROVED BAUXITE AREAS

The Midway-syenite contact shown on the subsurface map of Fig. 2 indicates the portions of the syenite that have protruded above the Midway clay and are therefore favorable for the occurrence of bauxite. It will be noted that all of the crosses indicating bauxite mines, and all of the bauxite ore bodies discovered and blocked out by the Bureau of Mines, fall within or very close to this contact line.

The depth of the Midway-syenite contact varies from 100 to 700 feet, depending on the configuration of the upper surface of the syenite and its relation to the southeastward dipping Midway clay. It is impossible to determine this line of contact from the geophysical data directly but the general form of the buried flanks of the syenite may be determined within certain limits. The quarter-mile spacing between the geophysical observation points is too large to expect faithful reproduction of the surface of an anomalous mass only a few hundred feet below the surface.

Referring now to the subsurface map of Fig. 2 and the gravity map of Fig. 4, it is evident that the gravimetric data indicate the syenite nose or ridge which projects east into Sec. 31, T. 1 N., R. 11 W., from the exposed syenite outcrop in Pulaski County generally referred to as Fourche or Granite Mountain. The broad valleys north and south of this ridge also show up very clearly in the gravity map.

The buried syenite ridge, which forms the southern tip of Fourche Mountain and which makes contact with the Midway clay in Sec. 28, T. 1 S., R. 12 W., and the deep valley along the western flank of this

ridge are indicated in the gravity data by pronounced reversals in the direction of the gravity contours.

On the magnetic map of Fig. 3 the abrupt changes in magnetic intensity over the same region indicate the shallow depth of the syenite.

The syenite high centered about Sec. 30, T. 1 S., R. 12 W., in Pulaski County, is indicated by a decided southward bulge in the gravity contours and by a distinct closed magnetic anomaly. These anomalies have already been considered in the discussion of Figs. 12 and 13 of this report.

The syenite high located north of Sardis, in Sec. 16, T. 2 S., R. 13 W., in Saline County, is faithfully represented by a closed gravity anomaly on a ridge extending eastward from the main syenite mass which is exposed south of Bauxite. Evidence of this high is also found in the magnetic data but the precise location of the part protruding through the Midway is not so clear.

The saddle or valley separating the Bryant (Alexander Mountain) syenite high from the larger high south of Bauxite is also quite evident in both the magnetic and the gravimetric data. The geophysical effect of the Alexander Mountain syenite high is more pronounced in the magnetic than in the gravimetric data.

The general configuration of the buried eastern flank of the Bauxite syenite outcrop is indicated in the form of the gravity contours and the abrupt changes in magnetic intensity indicate the shallow depth of the syenite in this locality.

The gravity picture of the southern end of the Bauxite syenite exposure is complicated and almost entirely masked by the regional eastward-trending gravity high which is believed to represent the effect of dense Paleozoic rocks of the Ouachita Mountain region which plunge beneath the Tertiary overburden.

The approximate position of the western flank of this large syenite mass can be deduced from both the gravimetric and magnetic data, but the picture is complicated by the intense anomalies due to the presence of what is believed to be a deep basic igneous plug centered in Sec. 30, T. 2 S., R. 14 W.

CONCLUSIONS

The geophysical surveys indicated that the syenite outcrops in Pulaski and Saline Counties with which the occurrence of bauxite is associated are domes or bosses on a large syenite batholith. The prob-

able presence of other domes of a similar nature on this batholith was deduced from the geophysical data and the drill proved the correctness of this interpretation. Of the 10 hitherto unknown domes proved by drilling only 2 protruded through the Midway formation and thus offered favorable conditions for the occurrence of bauxite. Incomplete drilling on these newly discovered favorable domes has found shows of bauxite, but no ore bodies have yet been blocked out in these localities.

All of the bauxite discovered and blocked out by the Bureau of Mines to date was found on the buried flanks of the syenite outcrops.

The results of the geophysical surveys are conclusive in that they indicate the improbability of the existence of other syenite masses offering favorable conditions for the occurrence of bauxite within the central Arkansas district.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to Mr. E. D. Gardner, Regional Engineer, and Mr. J. R. Thoenen, District Engineer, for valuable advice and criticisms during the course of the bauxite exploration program and the preparation of this report. Particular credit is due to the members of the staff of the Bureau of Mines bauxite project for their loyalty and cooperation, and to the members of the Federal Geological Survey field party under the direction of R. P. Bryson and Mackenzie Gordon, Jr., for their helpful aid and cooperation.

The magnetic survey was made under the direction of A. E. Brayton and Milton H. Rogers, and the gravity survey was directed by Matthew T. Murray, all of the Heiland Research Corporation and associated companies.

Drilling is being conducted under contract by the National Geophysical Company and Ainsworth Bros., Inc.

ADDENDUM

A recent paper by Romberg and Barnes[15] describes the results of a gravity survey over a granitic intrusion which also shows a negative gravity anomaly.

Quantitative calculations by these authors showed that the recorded anomaly of approximately −7 milligals could be explained by a granite mass having the approximate shape of a truncated cone extending from the surface, where it has a radius of

[15] Romberg, Frederick, and Barnes, Virgil E. *Correlation of Gravity Observations with the Geology of the Smoothingiron Granite Mass, Llano County, Texas.* GEOPHYSICS, Vol. 9, No. 1, January, 1944.

approximately 3 km, to a depth of approximately 1½ km where its radius increases to 4 km. The assumed difference in density between the granite and the enclosing rocks was 0.13, the granite being the lighter.

For the purpose of comparison of the gravity effects over the Little Rock batholith with those published for the Smoothingiron granite mass, rough quantitative calculations were made based on the following assumptions:

1. Mean density of overburden	2.0
2. " " " syenite	2.52
3. " " " Paleozoic rock	2.60
4. Average thickness of overburden over batholith proper	1000 feet.
5. Maximum observed negative gravity anomaly	−27.5 milligals
6. Means radius of batholith	40,000 feet
7. Gravity datum of 650 units over Paleozoic rocks.	

The results of these calculations were as follows:

1. Maximum gravity anomaly due to overburden covering Paleozoic rocks	−6.5 milligals.
2. Maximum gravity anomaly due to syenite batholith intruded into Paleozoic rocks	−21.0 milligals
3. Possible order of magnitude of thickness of syenite	60,000 feet.

It is obvious that the relative densities of the syenite and Paleozoic or pre-Paleozoic rocks may change considerably in both horizontal and vertical directions. Likewise the shape of the batholith is probably elliptical rather than cylindrical as assumed, and its upper surface is obviously irregular. Little would be gained by attempting to make more accurate calculations on the basis of more detailed assumptions. The thickness of the batholith is only of academic interest and the results given herewith seem quite adequate to support the contention made that this intrusive mass is a true batholith extending to profound depth.

ANALYTICAL AND EXPERIMENTAL DATA CONCERNING A SOLID HYDROCARBON SURVEY OF THE FORT COLLINS ANTICLINE*

R. MAURICE TRIPP†

ABSTRACT

An analysis is made of the properties of sediments and their derived products which pertain to the migration of gaseous hydrocarbons. From a thermodynamic consideration the zone of secondary mineralization is localized and the appearance of radioactive highs over structure is possibly explained.

A distinction is made between the types of soil waxes, and an hypothesis is advanced to explain the origin of the petroleum derived waxes.

The results of a soil wax survey of a producing structure are presented and discussed. No implication is intended regarding the general usefulness of the technique.

FOREWORD

It is not the intention of the present report to convey the impression that geochemical means offer a panacea for all prospecting ills. Instead, an attempt is being made to correlate the analytical and experimental results of some laboratory and field data in the hope of establishing the usefulness of the technique. It should be clearly understood that no broad generalizations are implied from the limited data presented.

INTRODUCTION

Many of the early successes in petroleum prospecting relied upon recognizing macro-seeps of oil and gas; therefore, it seemed advisable to investigate the possibility of micro-seeps over other accumulations which might be detectable by physical or chemical means.

In 1930 V. A. Sokolov, a young Russian nuclear physicist, and a coworker, M. G. Gurevitch, devised an apparatus for measuring the minute quantities of gas liberated during the radioactive disintegration of certain elements. The possibility of micro-gas seeps existing over oil reservoirs occurred to them and tests were made at Grozny[1] and Baku with their new apparatus. At about the same time the idea occurred to G. L. Hassler in this country and to G. Laubmeyer[2] in

* Presented at the thirteenth annual meeting, Ft. Worth, Texas, April 1943.

† Colorado School of Mines, Golden, Colorado.

[1] Sokolov, V. A. *New methods of prospecting for oil and gas deposits.* Trudy Neftyanoi, January, 1933.

[2] Laubmeyer, G. *A new geophysical prospecting method.* Petroleum, vol. 29, no. 18, May, 1933, pp. 1–4. See also U. S. Patent #1,843,878, Application filed Dec. 3, 1929.

Germany. The work of the three different men consisted in analyzing the free soil gas for hydrocarbon constituents. Hassler's results were disappointing. The other two were enthusiastic about their first results, but no discoveries to my knowledge have been reported by this means.

About 1937, E. E. Rosaire[3] introduced the technique of taking soil samples rather than gas samples in the field and then removing the entrained, occluded, and adsorbed gas with suitable reagents in the laboratory.

The physio-chemical properties of sediments and soil have suggested the advisability of determining a derived product of the escaping gases rather than the gas itself. The following discussion is therefore concerned with some of the properties of sediments which limit the usefulness of the various geochemical techniques.

ANALYTICAL DATA

Permeable Nature of Sediments

Permeability is a measure of the ease with which fluids may traverse a medium under the influence of a pressure differential. No substance is absolutely impermeable. In a medium composed of many discrete particles such as a sedimentary rock, the permeability is a function of the pore dimensions and is proportional to the square of the particle radius. Porosity is a measure of the pore space and varies from forty per cent for coarse sand to as high as ninety per cent or more for finer silts with particles less than .002 millimeters in diameter. Sands of medium sized grains will show the minimum porosity found in nature and this porosity varies little with depth. Shales, on the other hand, generally show high porosities during sedimentation because of their somewhat colloidal nature and their heterogeneous array resulting from their non-uniform shape. Shale porosities are rapidly decreased by compaction from the weight of overburden according to the following equation determined by Athy.[4]

$$f = f_0 e^{-bz} \qquad (1)$$

where f = porosity of shale
f_0 = average porosity of surface clays
b = a constant
z = depth of burial

[3] Rosaire, E. E. *Shallow stratigraphic variations over Gulf Coast structures.* GEOPHYSICS, vol. 3, no. 3, 1938, pp. 96–115.

[4] Athy, L. F. *Density, porosity, and compaction of sedimentary rocks,* A.A.P.G., vol. 14, no. 1, 1930.

At a depth of 5000 feet a shale may have been compacted to nearly fifty per cent of its original volume and its porosity reduced to less than one per cent. A sediment of this nature is generally considered impervious; however, under a sufficient pressure head and over long periods of time, substantial quantities of gas may be forced through the formation,

There must be free circulation of fluids vertically across the bedding, even though shales are considered impervious, because formation pressures are equal, with rare exceptions,[5] to the hydrostatic head to be expected at that depth. The hydrocarbon gases associated with petroleum are free to move in any direction from the reservoir rock but if there is local deformation or faulting, creating zones of lower pressure, the gases will probably migrate in that direction much more rapidly than they will through a relatively impervious overlying shale. If the hydrocarbons move up-dip into a structural trap, they cannot escape through the overburden as rapidly as they accumulate. However, the only negative pressure gradient at this point is vertical. Therefore, subsequent movement must be toward the surface and the mass rate of flow of gas may be expressed by a modified D'arcy's equation providing the pressure decline is not too rapid. The equation is as follows:

$$Q' = \frac{K\delta_0 A}{\mu(1+m)L_n}\left[p_1^{(1+m)} - p_n^{(1+m)}\right] \qquad (2)$$

where Q' = flow of gas in grams per second
K = permeability in darcys
δ_0 = density of gas in gms-cm^{-3}
A = cross sectional area of flow in cm^2
μ = viscosity of gas in poises
m = the thermodynamic character of the expansion of the gas; for isothermal $m = 1$, for adiabatic m = specific heat at constant volume divided by specific heat at constant pressure
L_n = distance from reservoir to surface in cm
p_1 = reservoir pressure in atmospheres
p_n = partial pressure of gas at surface in atmospheres.

A rigorous solution should involve the integration of the permeability and pressure drop across each lithologic unit in the geologic

[5] In some areas of recent emergence or submergence temporary erratic formational pressures may exist due to the time lag for fluids to adjust themselves to deformation.

section. For practical reasons this is impossible; therefore, an effective average value of permeability for water saturated sediments is used.[6]

A particular solution of Eq. 2 using very conservative values for the reservoir properties of the Fort Collins anticline (see section on reservoir data) gives the following results.

If K is taken equal to 10^{-7} darcys,

δ_0 for methane $= 7.17 \times 10^{-4}$ grams per milliliter,

A is taken equal to one square yard,

μ of methane at 20° C $= 120 \times 10^{-5}$ poises,

m = approximately 0.86,

$p_1 = 138.5$ atmospheres[7]

p_n = something less than 1 atmosphere, can be neglected in calculation

$L_n = 4500$ feet

with the above numerical values, Eq. 2 becomes,

$$Q' = \frac{10^{-7} \times 7.17 \times 10^{-4} \times (2.54 \times 36)^2}{120 \times 10^{-6} \times 1.86 \times 4500 \times 2.54 \times 12} (138.5)^{1.86}$$

$= 1.75 \times 10^{-4}$ gms per sec per square yard

= 376 cubic feet of methane per square yard per year at the mean temperature of 53° F.

The increased density and decreased viscosity of ethane over methane would account for a 22 per cent greater rate of diffusion of ethane. Methane is probably more significant, however, because of its predominance in natural gas. On the other hand, methane does not have a unique source in petroleum which makes it a poor index as to possible petroleum accumulation.

Secondary Mineralization

A thermodynamic consideration of the migrating gas and its influence on the sediments is of interest. Measurements of the geothermal gradient at Fort Collins indicate an average gradient of .0337°F per foot of depth. The mean air temperature is 52.6°F. The pressure gradient is approximately .0306 atmospheres per foot of depth. The

[6] Sokolov found the effective gas permeability of the average sedimentary section to be 10^{-7} darcys from his gas analysis work in Russia. V. A. Sokolov. *Gas Surveying*. Moscow, p. 28.

[7] This would be the pressure corresponding to the hydrostatic head at the depth of the reservoir. Reference to the initial production figures at Fort Collins shows that pressures greater than this must have existed.

mean surface pressure is .816 atmospheres. One cubic foot of methane in the Muddy sand would have a temperature of 205°F and be under a pressure of 138.5 atmospheres. If allowed to migrate vertically through the overlying sediments, the condition of state at any depth may be represented by the following equation:

$$PV = nzRT$$

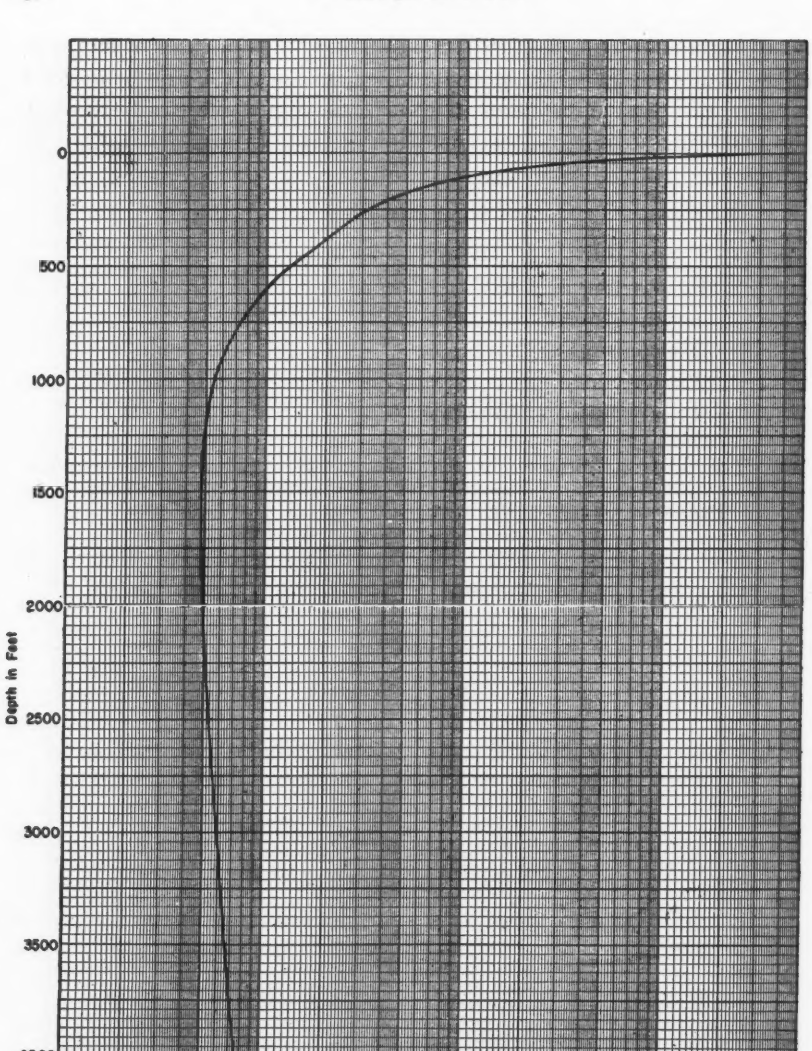
where P = pressure
V = volume of gas
n = mol fraction
z = compressibility factor[8]
R = universal gas constant
T = absolute temperature.

TABLE I. H_2O VAPOR CONTAINED BY .3045 MOLS. OF CH_4 AT SPECIFIED DEPTHS WHEN MIGRATING VERTICALLY THROUGH THE SEDIMENTARY COLUMN UNDER A PRESSURE GRADIENT OF .0306 ATMOSPHERES PER FOOT AND A THERMAL GRADIENT OF .0337° F PER FOOT

Depth in feet	*Temp. °F.*	*Abs. Press. in Atmos.*	*Comp. Factor*	*Relative Vol. of CH_4 in Ft^3*	*Total Vol. H_2O Vapor $Ft^3 \times 10^3$*
0	52.6	.816	.999	139.3	2370.0
10	53.0	1.122	.997	101.1	1212.0
25	53.5	1.578	.996	71.5	451.0
50	54.4	2.343	.995	48.5	272.0
100	56.0	3.88	.991	29.2	102.0
250	61.5	8.46	.983	13.4	26.1
500	70.4	16.10	.971	7.11	15.5
1000	86.2	31.40	.948	3.66	5.3
1500	104.0	46.75	.934	2.50	4.8
2000	120.0	62.0	.926	1.92	5.1
2500	137.7	77.4	.922	1.58	5.5
3000	153.6	92.6	.924	1.36	6.0
3500	171.2	107.9	.929	1.20	6.7
4000	187.3	134.2	.933	1.09	7.6
4500	205.0	138.5	.938	1.00	9.5

Table I is a summary of the solution of this equation for various depths, and Fig. 1 is a plot of the water vapor data of Table I. The volume of CH_4 at reservoir depth was taken equal to one cubic foot, and the water vapor content was determined from the experimental

[8] Determined from experimental data of Buderholzer, Sage, and Lacey. *Phase Equilibria in Hydrocarbon Systems.* Jour. of Ind. and Eng. Chem., vol. 31, p. 369.



WATER VAPOR CONTENT OF .3045 MOLS OF SATURATED METHANE VERSUS DEPTH

FIG. 1. Water vapor content of 0.3045 mols of saturated methane as a function of depth. (See Table I.)

data of Olds, *et al.*,[9] when the temperature and pressure were known at the respective points along the stratigraphic column.

Attention is drawn to the fact that water vapor is being condensed from the gas during the lower 3000 feet. More important still is the fact that 81 per cent of the total water evaporated from the formations comes from the twenty-five feet immediately below the surface.

The evaporation of these connate waters might cause the concentration of dissolved mineral matter to such an extent that the very insoluble material would be precipitated in the interstices of the rock. Many of the minerals which contain radioelements have an extremely low solubility product which suggests that they would probably be precipitated if appreciable evaporation took place. The result would be a concentration of radioactive minerals in the near surface over areas of high rates of gas migration.

Evidence of this secondary deposition of minerals is found from a study of the mineral content of oil field waters. In the Rocky Mountain area, petroleum never occurs where the formation waters have lower than two thousand parts per million of dissolved salts. It is also characteristic to find much higher salt content associated with high production.

Migration in the Vadose Zone

When the vertically migrating gases have reached the water table they are no longer impelled by the pressure differential because it becomes zero at this interface. The forces which act upon the gas in the vadose zone are mostly transient and may be directed either up or down. The motivating energy may be fluctuations in barometric pressure which can allow soil gas to escape or be forced back into the pores. Daily changes in temperature produce similar results. Gravity seepage of meteoric water will produce a downward movement of entrained gas and at the same time displace other gas which is in turn forced upward. Sunlight and wind cause a capillary movement of ground water to the surface which is accompanied by the movement of dissolved hydrocarbons. The oscillatory nature of these forces may allow the gases to remain in the zone over extended periods of time.

The texture and composition of the soil and rock in the vadose zone may greatly modify the the effectiveness of these transient migratory influences.

[9] Olds, Sage and Lacey. *Phase Equilibria in Hydrocarbon Systems*. Jour. of Ind. and Eng. Chem., vol. 34, p. 1223.

Adsorption Characteristics of Soil

Soil may be considered as a colloidal system whose properties are varying geographically and with time. The mineral constituents may vary over an extremely wide range in soils which appear to be relatively similar. The amount of gas adsorbed by the soil particles is a function of the partial pressure of the gas, the total surface area, the temperature, the structure of the solid surface, the presence of other adsorbable constituents or impurities, and the free surface energy of the mineral grains composing the soil. For small partial pressures the gas may be considered as forming a unimolecular film on the particles.

The specific adsorptive power of the mineral grains is dependent largely upon the free surface energy of the mineral which is a function of the attractive forces holding the atoms in the space lattice. At the surface of the solid these forces are directed partly to the interior and partly to the exterior. Only the former are saturated. The attractive force of the solid for the gas molecules depends largely upon this unsaturated condition. The magnitude of the unsaturation is expressed as the free surface energy and is found to vary with the nature of the compound and the relation of the surface to the symmetry of the crystal lattice.

The presence of a third substance may alter the gas-solid attractive forces also. The foreign substance may be another solid in close proximity or a second gas. For a more detailed discussion of this property refer to Freundlich, *New Conceptions in Colloidal Chemistry*, E. P. Dutton and Company, New York.

It has been shown experimentally that some soils having the same particle size but being composed of different mineral constituents have a difference in adsorption ability to hydrocarbon gases of from twenty to forty times. Pirson[10] reports a variation of twenty times in the amount of ethane adsorbed by two samples of different surface chemical nature.

A realization of these possible interfering factors on the interpretation of soil gas analyses led to a consideration of other means for detecting the escape of the hydrocarbon gases from subsurface reservoirs. A quantitative determination of soil wax is not seriously influenced by the above factors as will be seen under a discussion of wax origin.

[10] Pirson, S. J., *Critical survey of recent developments in geochemical prospecting.* A.A.P.G., vol. 24, no.8, p. 1466.

Composition and Origin of Soil Wax

Soil waxes have a rather complex nature. For prospecting purposes they can be divided into two classes. In the first class are those of definite surface origin which are derived from plants and animals. The second class includes those waxes derived from the gaseous hydrocarbons which have migranted from the subsurface reservoir to the surface. This latter group will be referred to as mineral waxes to distinguish them from the vegetable waxes.

The vegetable waxes have no apparent relationship to subsurface accumulations of petroleum; however, it is possible that they might reflect surface structural conditions. This is due to the fact that different plants prefer different soil types and some plants have a much higher wax content than others. Therefore, soils derived from a sandstone outcrop might support a type of plant high in wax content while that plant would not grow in the adjacent soil derived from limestone, thus producing a wax-high over the sandstone derived soil. It is interesting to note that higher wax concentrations have been encountered in the Pre-Cambrian crystalline rocks of the Front Range than in the sediments over a producing structure a few miles to the east. The waxes from the crystalline rocks appear to be of vegetable origin, however.

It has not been possible to determine the exact composition of these soil waxes because of the limitations of present organic analytical technique. However, it is believed that the vegetable waxes are higher alcohols, fatty acids, aldehydes, ketones, or a mixture thereof. The reason for this belief is that it is possible to extract such compounds from growing plants and they have physical properties similar to the residue obtained from some soil extractions. At the present, we believe the mineral waxes to be heavy aliphatic hydrocarbons. They have a definite paraffin-like appearance, are straw-colored to light brown, and have a melting point at about 66°C. It has not been possible up to the present time to make a clean chemical separation of these waxes on a micro-scale.

The question naturally arises as to how the hydrocarbon gases can produce the heavier solid hydrocarbons. Several reaction mechanisms have been suggested, but one process seems much more likely than all the rest. Investigations under way in our laboratories and experiments completed several years ago by Lind[11] showed that hydrocarbons were

[11] Lind, S. C., and Glockler, G., *Condensation of hydrocarbons by alpha rays*. Jour. of Amer. Chem. Soc., 52, p. 4450, 1930.

readily ionized by alpha radiation. There is reason to believe that double-ion clusters are subsequently formed which condense to form larger hydrocarbon molecules. The larger molecules are in turn ionized by direct impact or electron transfer to form new clusters which result in larger heavy molecules. Beginning with any paraffin hydrocarbon, exposure to alpha radiation results in the elimination of free H_2 and CH_4 and a building up of the higher members by ionic condensation. The heavier the initial hydrocarbon, the more liquids and solids which are formed by a given amount of radiation. Some solid and liquid, but no gaseous, olefins are formed.

Table II is a typical analysis of the reaction products resulting when 32.92 milliliters of gas at 25°C containing ethane and .0922 curies of radon were allowed to react for 72.17 hours or until the radon had reached approximately one half its original value.

TABLE II. PRODUCTS OF ETHANE-RADON REACTION[12]

Percent of carbon atoms reacting	26.6%
Percent of reacting carbon going to liquid	60.1%
Percent of reacting carbon going to gas	39.9%
Composition of gaseous phase	
H_2O	5.68%
CH_4	2.92%
C_2H_6	82.71%
C_3H_8	2.14%
C_4H_{10}	5.81%
C_5H_{12}	.56%

Nearly all the rocks in the earth's crust contain some radioactive minerals. The mean radium content is about 1.3×10^{-12} grams of radium per gram of rock. The acidic igneous rocks have a much higher content than the basic, and the metamorphic and sedimentary rocks vary according to their source material. Some of the dark shales have the highest measured radium content of any rock, 20×10^{-12} grams per grams of rock. Pure rock salt has the lowest radium content with pure limestone next. Shaley lime may have a higher value than normal. Sandstone varies according to its relative purity. Pure quartz sand is very low while argillaceous sand may be high. The radioactive mineral content of the sediments is usually found to be inversely proportional to the particle size.[13]

The formation of soil from parent rock is accompanied by a leach-

[12] See Lind and Glockler's report for experimental details.

[13] See Weaver, P., *Theory of the distribution of radioactivity in marine sedimentary rocks*. GEOPHYSICS, vol. VII, No. 2, 1942.

ing of the more soluble minerals and a residual enriching of the very insoluble minerals. Such a process favors the accumulation of radioactive minerals in the soil profile.

Radon gas is continuously evolved from any radium present, which in turn is a disintegration product from the uranium-containing minerals of the soil.

The concentration of radon in soil gases depends on the radium content of the parent rocks and the climatic conditions. Rain and frost tend to retard its escape, whereas strong sunlight, wind, and low barometric pressure facilitate its escape into the atmosphere. The average radon content of soil gas as given by Hevesy and Paneth[14] amounts to 5.66×10^{-9} curies per cubic foot. For the more radioactive dark shales as much as 8.72×10^{-8} curies per cubic foot of soil gas is encountered. From a consideration of the radon content of the atmosphere and the above statistical values it can be calculated that 1.66×10^{-4} curies of radon are diffusing into the atmosphere from one square yard of black, shale soil per year.

The effect produced by radioactivity is a product of time and radioactive element concentration. From the laboratory experiment previously cited 9.22×10^{-2} curies of radon were mixed with ethane for three days and appreciable heavy hydrocarbons resulted. By comparison it is not unreasonable to assume that the mineral waxes have been formed from the gaseous hydrocarbons which have migrated from below and have been adsorbed on the soil particles. Alpha rays emitted during the disintegration of minute concentrations of radioactive compounds in the space lattice of the mineral grains composing the soil, produce ionization of the adsorbed gas and a subsequent condensation reaction.

Actinic energy, the presence of certain metallic ions, or some other factor unique in the surface environment must act as a "conditioner" for the reaction; or perhaps some aerobic soil bacteria consume the hydrocarbons formed at greater depth nearly as rapidly as they are produced. The net result is that the mineral wax concentration appears to be greatest in the surface soil.

The occurrence of a hydrogen high over a petroleum accumulation high as reported by Horvitz[15] is easily accounted for from a condensation reaction that liberates H_2 and CH_4.

[14] Hevesy, George and Paneth, F. A. *A Manual of Radioactivity*. Oxford Univ. Press, 1938.

[15] Horvitz, L. *Method of Exploration for Buried Deposits*. U. S. Patent No. 2,183,964.

FIELD DATA

Area of Experimental Work

The field work in connection with these geochemical studies has been carried out on the Fort Collins anticline. This field was selected because of its well known structure, its small size, and because the outcropping formation is a dark shale with a relatively high radioactivity which weathers to a soil of fairly uniform texture and composition over the entire area.

Location of Structure

The Fort Collins anticline is situated in Larimer County, Colorado, beginning about two miles north of the town of Fort Collins and extending in a northerly direction approximately five miles. The structure is the southern knob of a sinuous ridge fourteen miles long located on the western central edge of the Julesburg Basin. (See Fig. 2 for the location of the structure in relation to the regional features.)

General Geologic Features

The area of closure is about $4\frac{3}{4}$ miles long by $1\frac{1}{2}$ miles wide and the vertical closure is approximately seven hundred feet. Production comes from the Muddy and Dakota sands at a depth of 4500 feet and the lateral extent of production includes 480 acres on the crest of the structure. The inner dotted line on Fig. 3 marks the limit of production. The beds on the west limb dip 10° to 15° westward; those on the east side dip eastward 6° to 10°. The regional dip is one thousand to twelve hundred feet per mile to the east.

The geologic section from the top of the Dakota to the surface consists of approximately 600 feet of Benton shale overlain by 400 feet of Niobrara limestone which in turn is covered by approximately 3500 feet of Pierre shale which is the surface outcropping formation. The Pierre is principally a dark non-calcareous shale with a few thin sandy and bentonitic layers.

Production and Reservoir Data

Initial production from the discovery well was 4580 barrels in twenty-four hours through a three inch tubing. There is no record available on the reservoir pressure at that time but it was evidently high judging from the large flow encountered. The producing horizon is eighteen feet thick and has produced through fifteen wells a total of

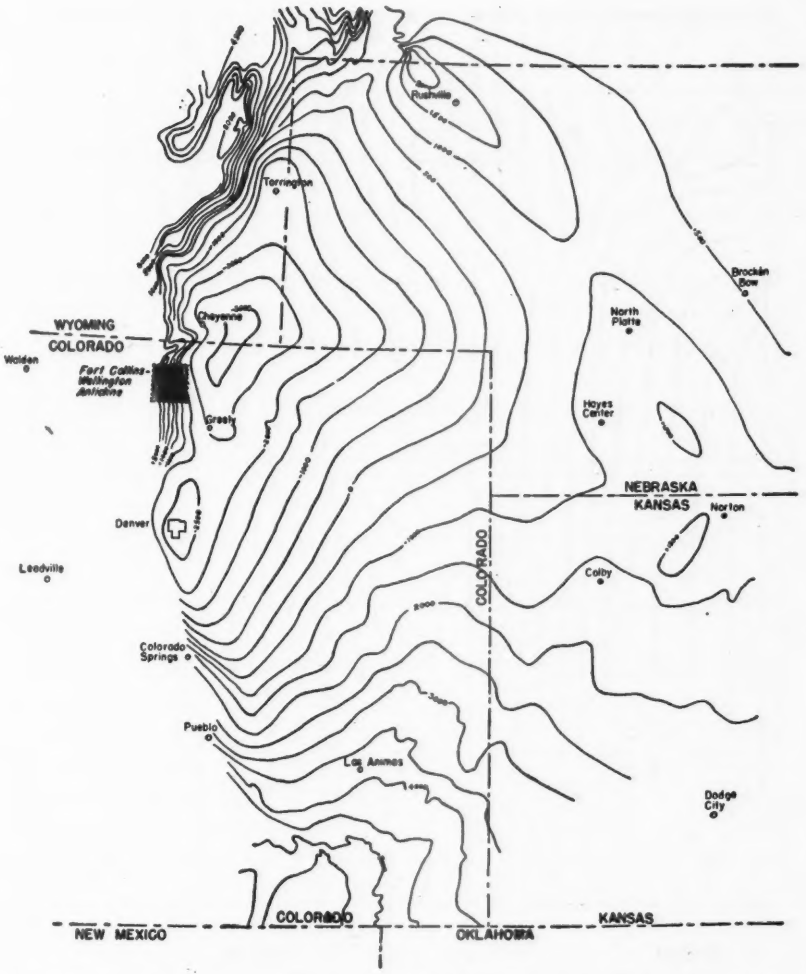


FIG. 2. Location of the Fort Collins anticline with respect to the Julesburg basin. Generalized contours on the Dakota sandstone. Contour interval is 500 feet.

2,186,812 barrels of crude from its discovery in 1924 up until 1940, or a natural recovery of over 4500 barrels per acre on a 40-acre well spacing.

In 1928 the Continental Oil Company started a small gas recycling project, using two input wells with a gas injection pressure of 275 pounds per square inch from a 100-horsepower plant. The daily gas cycle is about 47,000,000 cubic feet.

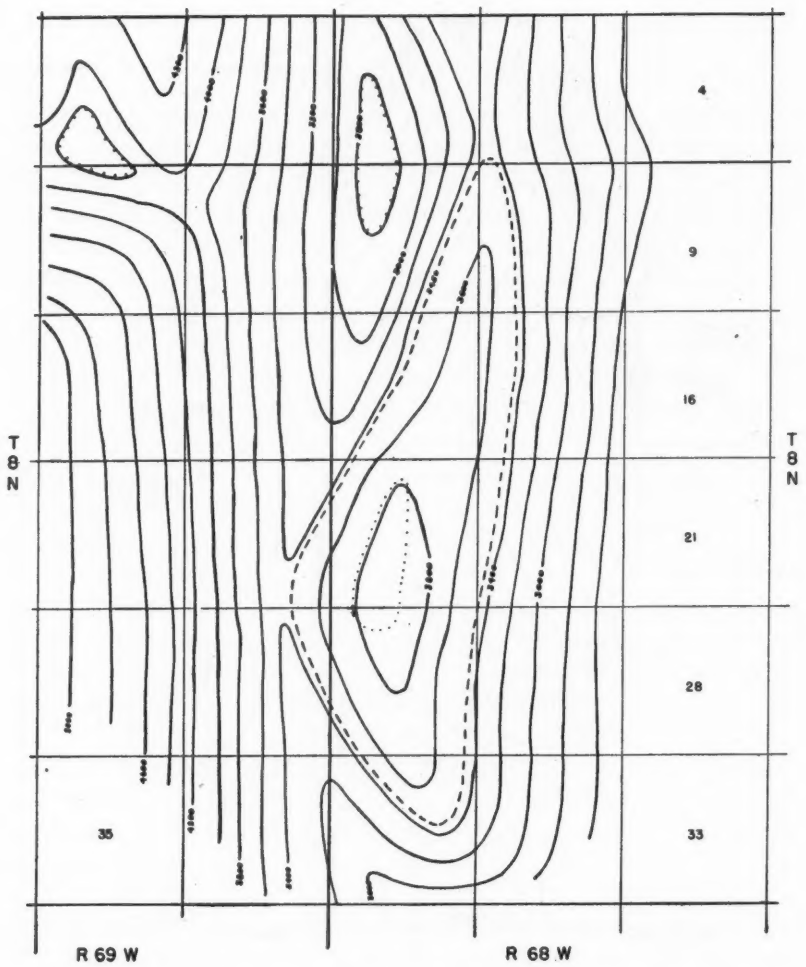


FIG. 3. Structure of the Fort Collins oil field, Larimer County, Colorado, contoured on a sandstone member of the Pierre shale by A. T. Schwennesen. Dashed line is the closing contour at 3450 feet, dotted line occupying part of the 3800 foot contour is the limit of production. Contour interval is 200 feet.

Fig. 4 shows the production graph of the field from 1925 to 1940. The rise after 1937 is a result of new production from deep Dakota sands. Future reserves in 1940 were estimated at 150,500 barrels assuming ten barrels per day from the field would be the economic limit of production.

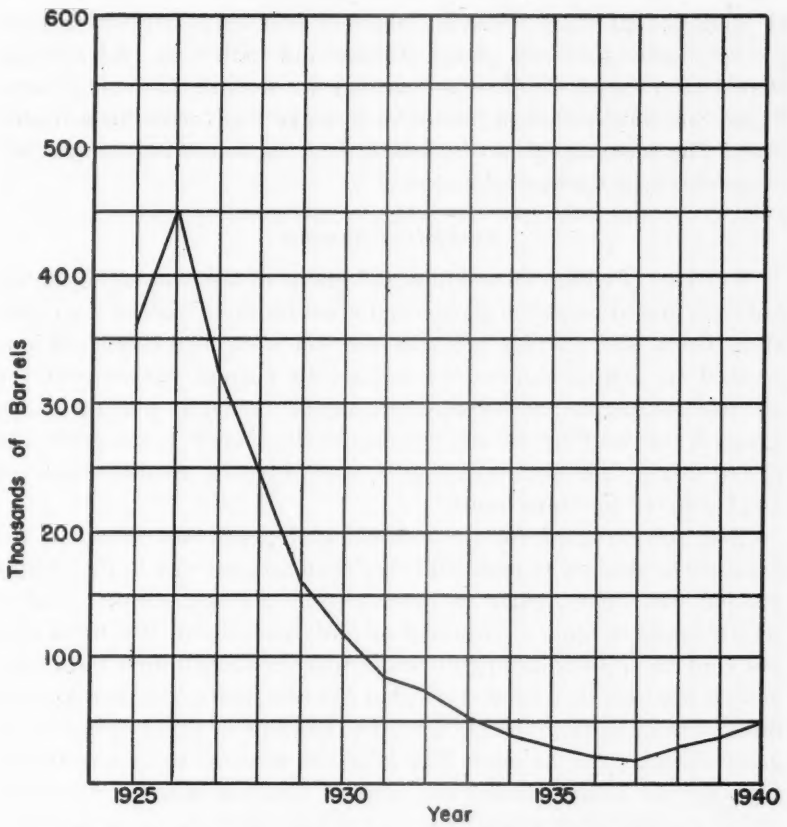


FIG. 4. Crude oil production from the Fort Collins field in thousands of barrels per year, by years. (After Barb.)

EXPERIMENTAL RESULTS

Collection of Samples

Samples were taken from the upper one-half inch only, partially because of bacterial action at greater depths. Surface contamination is likely in the shallow samples, but by careful collection this factor was thought to be reduced below the limits of error of the analysis. Samples were taken in five parts; one-fifth at the selected point and the four remaining portions were collected four feet from it, one in each quadrant.

Great care was taken to insure relative uniformity among all samples as to soil composition, texture, and moisture content. It should

be obvious that exact similarity between samples is impossible since the soil varies infinitely geographically and with time. All samples were characteristically fine arenaceous loam with two exceptions. These contained sufficient bentonite to make them resemble a friable shale. The topography is very gentle and the soil is mostly residual except for minor eolian additions.

Analysis of Samples

Portions of eighty to one hundred grams of the thoroughly mixed soil were placed on watch glasses and dried for three days at a temperature below the melting point of the soil wax. The dried soil was crushed to particle dimensions and an air current passed over the agitated sample to remove as much organic debris as possible. Fifty grams of the resulting soil was weighed to the nearest 1/100 gram and placed in a soxhlet extractor with 150 milliliters of a suitable solvent and extracted for three hours.

The solvent used for the extraction depends somewhat on the presence or absence of material other than mineral wax in the sample and on what one desires to extract from the soil sample. Carbon tetrachloride or other chlorinated solvents are suitable if the soil does not contain appreciable quantities of waxy material other than mineral, as distinguished from the higher alcohols, aldehydes, and ketones derived from surface plants. Similarly, benzene or other aromatic organic solvents can be used. The aliphatic solvents have a relatively high solvent action toward the mineral wax and a lower dissolving power toward other waxes. For that reason they are to be preferred in most cases. Compounds lighter than pentane have a progressively lower solvent ability and are too volatile to handle easily. Compounds heavier than octane are difficult to evaporate satisfactorily. For routine extractions pentane or hexane appear to be preferable to all others because they have a boiling point below the melting point of the mineral waxes and also have a sufficiently high solvent power. If appreciable amounts of vegetable waxes are present, it is usually desirable to use a synthetic solvent with higher selective solvation.

The solvent containing the dissolved wax was evaporated to a volume of ten milliliters and the concentrate filtered into a dropping funnel. The solvent was evaporated off by dripping the concentrate into a porcelain microcrucible submerged in a water bath. The wax residue was then determined to the nearest 1/100,000 of a gram on an assay balance. Fig. 5 is a schematic flow sheet of the analytic procedure.

Discussion of Results

The wax content of the samples is expressed as parts per million by weight of the original sample and plotted on a map of the area at the point where sample was taken. Fig. 6 was obtained by contouring points of equal wax content. The string of high values along the road from station 49 to 38 is possibly the result of surface contamination. Between station 37 and 38 is a small refinery which delivers to tank

TABLE III. RESULTS OF SAMPLE ANALYSIS

Station No.	*Mg of Wax/50 gm*	*Station No.*	*Mg of Wax/50 gm*	*Station No.*	*Mg of Wax/50 gm*
1	3.77	20	2.06	39*	184.24
2	2.82	21	4.74	40	5.33
3	3.02	22	2.51	41	6.83
4	4.50	23	3.21	42	2.46
5	2.95	24	1.95	43	2.76
6	2.16	25	6.35	44	3.69
7	5.06	26	9.50	45	5.38
8	7.06	27	5.66	46	4.05
9	3.16	28	2.89	47	1.52
10	2.40	29	3.14	48	8.18
11	5.66	30	2.74	49	7.04
12	5.34	31	1.71	50	1.53
13	8.78	32	2.70	51	3.51
14	4.50	33	4.03	52	4.56
15	3.86	34	2.28	53	3.02
16	3.16	35	5.25	54	6.82
17	5.10	36	6.66	55	4.70
18	2.72	37	9.38	56	2.68
19	3.77	38	9.34	57	3.41

* Known to be contaminated with grease when sample was collected.

trucks which drive west two miles and then turn south onto the highway. If there was any spilling when the truck was being filled there might be misting over the surrounding area as it drove away. For that reason the wax-analysis values from station #38 westward have been neglected in contouring the map. In addition, the residue from sample #39 was found to contain a gum which was present in the order of twenty times the magnitude of the highest wax concentration. This analysis was omitted from the map. Sample #26, taken at the center of the south line of Sec. 34, suggested a minor contamination with vegetable wax.

When this iso-wax map is compared with the structural map of the area (Fig. 3) a remarkable similarity is seen to exist. However, there is a shift of the iso-wax axis about 7000 feet to the northeast. A completely satisfactory explanation for this lateral shift is not apparent. If it is assumed that the lighter hydrocarbons migrate from the reservoir to the surface normal to the bedding, then a shift of approximately 1500 feet can be accounted for. The following possibility also exists

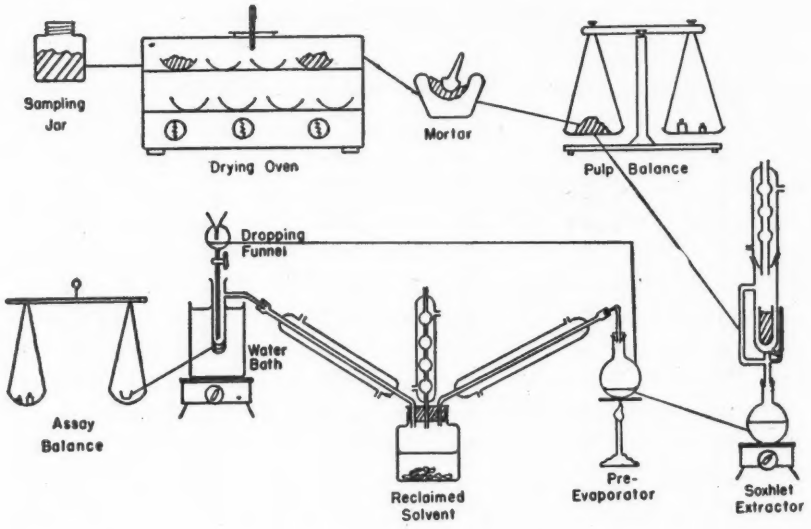


FIG. 5. Schematic flow sheet of the analytic procedure used in making the wax analyses.

but there are no field measurements to verify it: If the hydrocarbon gases are held in solution by the formation fluids and the fluids are moving down dip from the outcrops eastward toward the basin, then the gas flux lines would follow a direction determined by the vector resultant of the vertical velocity of gas migration and the lateral velocity of fluid migration. No information is available regarding the movements of formational fluids in the vicinity but it is reasonable to believe that meteoric water may be entering at the outcrop and moving down the relatively steep regional dip of 1200 feet per mile toward the basin.

It might appear from the analytical treatment of gaseous adsorption earlier in the paper that a correction should be made for the variation in total surface area of the sample, or that the residue should

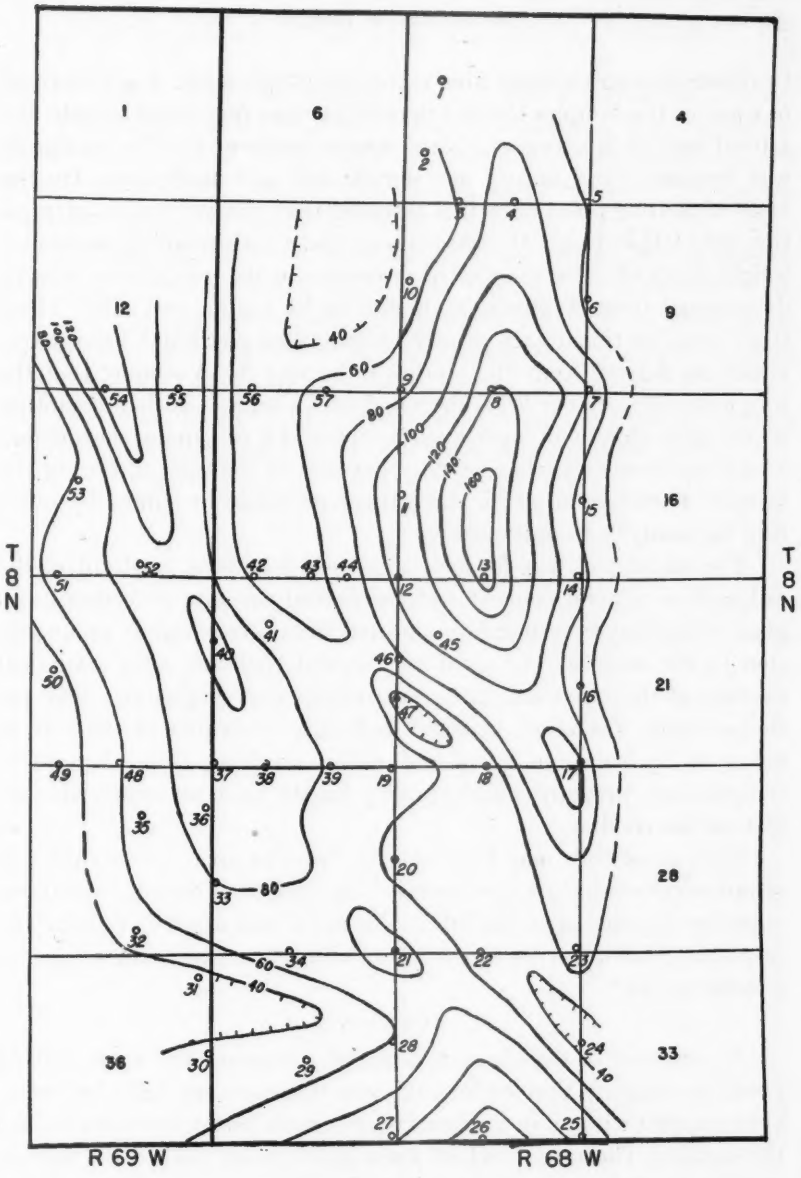


FIG. 6. Iso-wax contour map of the Fort Collins oil field, Larimer County, Colorado. (See Table III for data.) Contour interval is 20 parts of wax per million parts of soil by weight. Values at stations 39, 38, 37, 48, 49 have been ignored in contouring.

be referred to unit surface area rather than unit mass. A size analysis of some of the samples showed that an average fifty gram sample had a total surface in excess of 4×10^4 square centimeters. The maximum wax content found in any one sample was 9.16 milligrams. On the basis of melting point data it is assumed that the wax has a composition near $CH_3(CH_2)_{28}CH_3$, triacontane, and a corresponding molecular weight of 422.8. The number of molecules in the wax residue can be determined from Avogadro's number to be 1.368×10^{19}. The "effective" cross sectional area of any hydrocarbon chain has been determined by Adam[16] from film studies to be 20.7 Å^2. Assuming that the wax molecules are one layer deep and are in contact with one another on all sides, they will cover a surface of 28.3×10^3 square centimeters which represents less than seventy per cent of the total surface of the sample. Therefore no particular advantage would be gained by referring the analysis to unit surface.

The amount of wax formed in the soil may be a resultant of the radioactive mineral content and the partial pressure of hydrocarbon gases which have presumably migrated from a reservoir of accumulation to the surface. The total wax should therefore be a statistical average of these two fluctuating quantities over a relatively long period of time. Therefore, seasonal and daily variations in the rate of efflux of hydrocarbon gases and radon resulting from changes in temperature, pressure, and humidity should have no appreciable effect on the results.

Since some soils may have several times as great a concentration of radioactive minerals as others, it is possible that serious limitations might be imposed upon the interpretation of wax analysis results. The results of a radon survey of the Fort Collins structure is the subject of another paper.*

SUMMARY

An analysis of the characteristics of sediments and their derived products suggests that under sufficient pressures the light hydrocarbons trapped with oil in a subsurface reservoir would be forced toward the surface. The rate at which these gases move toward the surface may be predicted from calculations involving the properties of the reservoir and overlying sediments. However, the movements of the gas in the vadose zone are not amenable to mathematical predictions

[16] Adam, N. K. *Structure of surface films on water.* Jour. Phys. Chem., 29, 87 (1925).

* Tripp, R. M. *A radon survey of the Fort Collins anticline.* Presented at the fourteenth annual meeting, Dallas, Texas, March 1944. To be published in GEOPHYSICS.

due to daily and seasonal variations in temperature, pressure, humidity, wind, and vegetational cover. For that reason a direct measurement of the rate at which the hydrocarbons are effluxing into the atmosphere is not a satisfactory criterion upon which to base deductions concerning petroleum accumulation.

Furthermore, the wide difference in adsorptive ability of various soil constituents to hydrocarbon gases renders the measurement of the adsorbed, occluded or entrained gases a quantity of questionable significance. It is postulated that soil waxes are derived from these effluxing gases and further that the amount of wax is a statistical function of the radioactive mineral content and the amount of gas passing through the soil averaged over a relatively long period of time.

PATENTS VESTED IN THE ALIEN PROPERTY CUSTODIAN*

O. F. RITZMANN†

Certain U. S. patents and patent applications belonging to nationals of enemy and enemy-occupied countries have been vested in the Alien Property Custodian. The office of the A.P.C. has stated three objectives in administering these patents; namely, to increase the effectiveness of our production, to stimulate research, and to develop new production techniques. It is understood that the patents are not for sale but that, upon meeting application requirements, the A.P.C. will grant licenses under the patents with certain conditions for a nominal fee, including $15 for each patent or patent application. A distinction is drawn in some respects between the patents vested from enemy aliens and those vested from the nationals of enemy occupied countries. Full information may be obtained from the Office of the Alien Property Custodian, Washington 25, D. C.

Printed copies of the individual patents and printed copies of drawings and specifications of vested patent applications may be obtained for ten (10) cents each from the Commissioner of Patents, U. S. Patent Office, Washington 25, D. C. Lists of vested patents and patent applications in each class of the Patent Office system of classification may be obtained at nominal charge, also a complete catalogue of all vested patents and patent applications for $7.00, from the office of the Alien Property Custodian, Chicago 3, Illinois. The vesting and cataloguing of these patents is a prodigious task and the A.P.C. office is to be commended on making the information available to the public in such convenient form.

The writer has extracted from the A.P.C. complete catalogue of over 25,000 those patents which might be of interest to geophysicists. This was done by going through those classes in which even one interesting patent appeared during the last two years. The numbers of any vested patents which appeared of interest were then copied and the patent examined in more detail. The resulting list is given below. It is perhaps somewhat more inclusive than needs be, but geophysicists' present interests are varied. There may be some omissions because titles and classifications are sometimes misleading.

* Reprints of this paper can be secured from the Society, at no charge, by the staff member of any geophysical group who is concerned with patent matters. (EDITOR)

† Gulf Research & Development Company, Pittsburgh, Pennsylvania.

The list of vested patent applications was considered more important because it contains the enemy's most recent inventions. Accordingly, this catalogue was gone over in entirety. Those whose titles looked interesting and all of the applications in the more pertinent classes were examined in detail. As this material is new and has not been previously available, the interesting applications have been abstracted and are given below.

The writer wishes to thank Dr. Paul D. Foote, Dr. E. A. Eckhardt and Mr. A. M. Houghton of the Gulf Oil Corporation for permission to publish this material.

LIST OF U. S. PATENTS PERTAINING TO GEOPHYSICS AND WHICH HAVE BEEN VESTED IN THE ALIEN PROPERTY CUSTODIAN

1,585,591. Means for Electric Proof and Measuring of the Distance of Electrically-Conductive Bodies. H. Lowy. Iss. 5/18/26. App. 7/17/23.

1,589,678. Removing Broken Tools from Bore Holes. T. Bornemann. Iss. 6/22/26. App. 8/24/21. Assign. A. Stahn.

1,592,816. Time Measuring Apparatus. T. Aoki and M. Hagiwara. Iss. 7/20/26. App. 7/30/24.

1,599,466. Motion Amplifying Device. C. E. P. Gourdou. Iss. 9/14/26. App. 5/5/24.

1,603,805. Filter Circuits. H. Riegger. Iss. 10/19/26. App. 8/8/22. Assign. Siemans & Halske.

1,603,806. Filter Chain. H. Riegger. Iss. 10/19/26. App. 8/8/22. Assign. Siemens & Halske.

1,606,807. Filter Chain. H. Riegger. Iss. 11/16/26. App. 9/21/22. Assign. Siemens & Halske.

1,608,169. Rotary Well Drilling Machinery. J. T. Hayward. Iss. 11/23/26. App. 5/18/23.

1,616,754. Galvanometer. R. Mechau. Iss. 2/8/27. App. 9/29/21. Assign. Carl Zeiss.

1,622,896. Device for Drilling or Chiseling Away the Rock. K. P. zu Lowenstein. Iss. 3/29/27. App. 9/17/25.

1,636,313. Sinking Shafts and Bore Holes. W. G. Minuth. Iss. 7/19/27. App. 3/18/25.

1,640,313. Device for Indicating and Recording the Specific Gravity of Gases. O. Dommer. Iss. 8/23/27. App. 2/5/25.

1,641,199. Recording System. E. Roucka. Iss. 9/6/27. App. 3/14/23.

1,647,894. Indicator. F. R. Wasserkampf. Iss. 11/1/27. App. 4/17/24. Assign. Neufeldt & Kuhnke, G.m.b.H.

1,649,378. Means for Sounding or Measuring Distance in Water. A. Behm. Iss. 11/15/27. App. 7/7/21.

1,652,255. Gravitation Meter for Measuring the Vertical Gradient of the Gravity of the Earth. W. Schweydar. Iss. 12/13/27. App. 4/9/27.

1,656,225. Electric Wave Filter. M. Osnos. Iss. 1/17/28. App. 2/20/23. Assign. G. f. Drahtlose Telegraphie m.b.H.

1,658,449. Fluid Level Indicator for High Pressure Vessels or Containers. S. Loffler. Iss. 2/7/28. App. 7/10/25.

1,688,034. Bore-Hole Apparatus. T. Zaluski. Iss. 5/1/28. App. 4/3/26.

1,672,328. Method of Electromagnetic Underground Prospecting. W. A. Loth. Iss. 6/5/28. App. 1/3/23.

1,681,460. Recording Device. F. W. G. Bruhn. Iss. 8/21/28. App. 2/1/27.

1,683,362. Fluid Level Indicator and Leading in Arrangement for Electrodes in Hot High Pressure Rooms. S. Loffler. Iss. 9/4/28. App. 5/22/25.

1,683,900. Safety Device for Blasting or Explosive Cartridges. E. Karollus. Iss. 9/11/28. App. 7/26/27.

1,684,229. Measuring Instrument. J. Koenigsberger. Iss. 9/11/28. App. 7/21/26.

1,685,534. Apparatus for the Separation of Oil from Oil-Containing Substances. C. Drahn. Iss. 9/25/28. App. 2/4/27. Assign. F. Krupp Grusonwerk A.G.

1,690,949. Apparatus for Measuring the Rate of Flow of Fluids. G. S. Albanese. Iss. 11/6/28. App. 6/7/24.

1,694,509. Tensiometer. W. Klemperer. Iss. 12/11/28. App. 11/12/25. Assign. Luftschiffbau Zeppelin Gesellschaft.

1,695,701. Sounding Device for Liquid Levels. L. Steiner. Iss. 12/18/28. App. 5/31/27. Assign. Siemens-Schuckertwerke.

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2,193,707. Acceleration Responsive Device. H. Baumann. Iss. 3/12/40. App. 11/24/37. Assign. Askania-Werke A.G.

2,198,278. Apparatus for Mesauring Accelerations and Retardations. G. W. Peter van der Heiden. Iss. 4/23/40. App. 3/22/38.

2,202,446. Pipe Grip. C. J. Esseling. Iss. 5/28/40. App. 11/7/39. Assign. N. V. Gebr. Stork & Co.'s. Fabriek van Hijschwerktuigen.

2,203,061. Apparatus Responsive to Accelerations. E. Schmettow. Iss. 6/4/40. App. 5/31/38. Assign. Siemens Apparate und Maschinen G.m.b.H.

2,205,022. Bore Hole Direction Tester. G. Tipter. Iss. 6/18/40. App. 12/27/37.

2,205,075. Variable Width Band Pass Filter. K. Wilhelm. Iss. 6/18/40. App. 7/10/37. Assign.Telefunken G. f. Drahtlose Telegraphie m.b.H.

2,206,507. Device for Breaking Froth. H. Kuhni. Iss. 7/2/40. App. 5/5/38. Assign. L'Air Liquide Societe Anonyme pour l'Etude et l'Explortation des Procedes Georges Claude.

2,207,829. Recording Instrument for Electrical Measurements. H. Sell. Iss. 7/16/40. App. 10/20/37.Assign. Siemens & Halske.

2,209,140. Damping Mechanism for Oscillating Systems.[1] I. Rybar. Iss. 7/23/40. App. 7/6/38. Assign ½ to Pracisions Mechanische A.G.

2,210,582. Method for the Extraction of Petroleum by Mining Operations. K. Grosse and G. Schlicht. Iss. 8/6/40. App. 9/12/38. Assign. Deutsche Petroleum A.G.

2,212,273. Arrangement for Measuring the Local Specific Resistance of Borehole Strata.[2] O. Martienssen. Iss. 8/20/40. App. 10/21/38.

2,212,274. Method of Exploring the Porosity of Geologic Strata Traversed by Boreholes. O. Martienssen.[3] Iss. 8/20/40. App. 10/21/38.

[1] Abstracted in GEOPHYSICS, October, 1940.
[2] Abstracted in GEOPHYSICS, January, 1941.
[3] Abstracted in GEOPHYSICS, January, 1941.

2,216,454. Volume Range Control Circuits. H. Pfister. Iss. 10/1/40. App. 2/5/38. Assign. Telefunken G. f. Drahtlose Telegraphie m.b.H.

2,218,295. Apparatus for Obtaining Core from Rotary Core-Boring. K. Nishio. Iss. 10/15/40. App. 11/7/38.

2,220,164. Device for Producing Vibrations. H. List. Iss. 11/5/40. App. 9/27/38.

2,221,681. Volume Control System. K. H. F. Schlegel. Iss. 11/12/40. App. 5/5/38. Assign. Electrical Fono-Films Co., A/S.

2,223,645. Well and the Like Sinking Apparatus. G. J. Solomon. Iss. 12/3/40. App. 12/6/37.

2,228,499. Apparatus for the Vibration Testing of Articles. F. Allendorff. Iss. 1/14/41. App. 12/23/37. Assign Robert Bosch G.m.b.H.

2,230,297. System of Translating the Minute Variation of Inductance or Capacity Into the Variation of Electric Current or Voltage. H. Inoue. Iss. 2/4/41. App. 9/26/39.

2,230,618. Method for the Investigation of Substances with the Aid of Slow Neutrons. H. I. Kallman and E. Kuhn. Iss. 2/4/41. App. 1/20/39. Assign. I. G. Farbenindustrie A.G.

2,235,003. Wave Filter Chain. M. Arends. Iss. 3/18/41. App. 3/14/39. Assign. C. Lorenz A.G.

2,242,312. Geophysical Apparatus.[4] L. Machts. Iss. 5/20/41. App. 5/28/38.

2,245,787. Examining Bodies by Means of Neutrons and Electron Emitting Material. H. I. Kallmann and E. Kuhn. Iss. 6/17/41. App. 5/27/39. Assign. I. G. Farbenindustrie A.G.

2,246,259. Apparatus for Making Geophysical or Other Measurements.[5] L. Machts. Iss. 6/17/41. App. 2/17/39.

2,246,443. Method and Device for the Investigation of Substances by Slowly Moving Neutrons. H. I. Kallmann and E. Kuhn. Iss. 6/17/41. App. 1/20/39. Assign. I. G. Farbenindustrie A.G.

2,246,887. Electrically Operated Device for Transmitting Angular Movement. A. Krussmann. Iss. 6/24/41. App. 10/3/40. Assign. Askania-Werke A.G.

2,248,272. Magnetizing of Annular Magnets. L. Jurak. Iss. 7/8/41. App. 2/23/39.

2,248,466. Band Pass Coupling Network. H. O. Roosenstein. Iss. 7/8/41. App. 9/17/38. Assign. Telefunken G. f. Drahtlose Telegraphie m.b.H.

2,248,653. Apparatus for Measuring the Amplitude of Oscillations. F. Allendorff. Iss. 7/8/41. App. 1/27/39. Assign. Robert Bosch G.m.b.H.

2,250,708. Time Interval Measuring Means. F. Herz. Iss. 7/29/41. App. 1/13/38. Assign. Telefunken G. f. Drahtlose Telegraphie m.b.H..

2,251,190. Method of Producing Neutrons. H. I. Kallmann and E. Kuhn. Iss. 7/29/41. App. 3/10/39. Assign. I. G. Farbenindustrie A.G.

2,252,059. Method and a Device for Determining the Magnitude of Magnetic Fields.[6] R. Barth. Iss. 8/12/41. App. 12/24/37. Assign. Siemens Apparate und Maschinen. G.m.b.H.

2,253,035. Apparatus for the Production of a Ray of Slow Neutrons. H. I. Kallmann and E. Kuhn. Iss. 8/19/41. App. 9/15/39. Assign. I. G. Farbenindustrie A.G.

2,270,373. Neutron Image Convertor. H. I. Kallmann and E. Kuhn. Iss. 1/20/42. App. 5/20/40. Assign. I. G. Farbenindustrie A.G.

[4] Abstracted in GEOPHYSICS, July, 1941.

[5] Abstracted in GEOPHYSICS, October, 1941.

[6] Abstracted in GEOPHYSICS, October, 1941.

2,272,375. Arrangement for Reproducing the Intensity Distribution in a Ray of Slow Neutrons. H. I. Kallmann and E. Kuhn. Iss. 2/10/42. App. 8/2/40. Assign. I. G. Farbenindustrie A.G.

2,274,901. Device for Showing the Distribution of the Intensity in a Neutron Beam. H. I. Kallmann and E. Kuhn. Iss. 3/3/42. App. 10/19/39. Assign. I. G. Farbenindustrie A.G.

2,279,023. Method and Device for Detecting Objects. H. I. Kallmann and E. Kuhn. Iss. 4/7/42. App. 10/19/39. Assign. I. G. Farbenindustrie A.G.

2,284,990. Method and Apparatus for Electrical Prospecting.[7] M. Schlumberger. Iss. 6/2/42. App. 7/5/39.

2,287,619. Device for the Production of Slow Neutrons. H. I. Kallmann and E. Kuhn. Iss. 6/23/42. App. 6/8/40.

2,288,210. Core Taking Projectile.[8] M. Schlumberger. Iss. 6/30/42. App. 5/3/39.

2,288,717. Method for the Investigation of Substances with the Aid of Neutrons. H. I. Kallmann and E. Kuhn. Iss. 7/7/42. App. 1/31/40. Assign. I. G. Farbenindustrie A.G.

2,288,718. Device for Measuring the Intensity of a Radiation of Slow Neutrons by Means of Ionization Chamber. H. I. Kallmann and E. Kuhn. Iss. 7/7/42. App. 1/31/40. Assign. I. G. Farbenindustrie A.G.

2,289,822. Automatic Audio Band Control. H. Boucke. Iss. 7/14/42. App. 5/24/41. Assign. Telefunken G. f. Drahtlose Telegraphie m.b.H.

2,297,251. Device for Measuring Displacements with Carrier Frequency. K. Schild. Iss. 9/29/42. App. 6/16/38.

2,297,398. Method of Receiving and Reproducing Fast Oscillations. G. Fries. Iss. 9/29/42. App. 1/12/40.

2,297,416. Examination of Substances or Bodies by Means of Neutrons and X-Rays. H. I. Kallmann and E. Kuhn. Iss. 9/29/42. App. 11/15/39.

2,297,436. Arrangement for Testing the Frequency Characteristic of Electric Transmission Devices. W. Scholz. Iss. 9/29/42. App. 10/24/39.

2,297,451. Method of Selective Filtering of Frequency Band Ranges. H. Bendel, K. H. Krambeer and H. Jacoby. Iss. 9/29/42. App. 5/4/40.

2,300,562. Fuel Container Sounding Device. E. Freystedt. Iss. 11/3/42. App. 5/8/40.

2,301,396. GravityMeter.[9] A. Graf. Iss. 11/10/42. App. 4/6/38.

2,304,394. Oil Well Tubing Coupling. J.G.A.M. Biermann and R. Schiel. Iss. 12/8/42. App. 11/7/39.

2,305,452. Method and Device for Depicting the Intensity Distribution in a Beam of Slow Neutrons. H. I. Kallmann and E. Kuhn. Iss. 12/15/42. App. 9/28/40.

2,306,888. Arrangement for Producing High Unidirectional Voltages. U. Knick. Iss. 12/29/42. App. 1/30/41.

2,316,987. Electric Device for Distant Indication. H. Pittet. Iss. 4/20/43. App. 3/6/41.

2,323,027. Drilling Implement. W. Gerstenkorn. Iss. 6/29/43. App. 9/25/41.

2,325,512. Audio Amplifier Response Control. W. Hepp. Iss. 7/27/43. App. 6/14/41.

2,328,496. Magnetostrictive Microphone. Y. Rocard. Iss. 8/31/43. App. 2/24/40.

2,329,570. Device for Regulating the Sensitivity of Signal Receiving Apparatus.[10] R. Wellenstein, W. Holle and M. Schumacher. Iss. 9/14/43. App. 4/4/40.

[7] Abstracted in GEOPHYSICS, October, 1942.

[8] Abstracted in GEOPHYSICS, October, 1942.

[9] Abstracted in GEOPHYSICS, April, 1943.

[10] Abstracted in GEOPHYSICS, January, 1944.

2,332,536. Electrical Circuit Control Device.[11] K. H. F. Schlegel. Iss. 10/26/43. App. 4/23/41.

2,332,953. Apparatus for Indicating and Adjusting the Specific Gravity of Suspensions. K. F. Tromp. Iss. 10/26/43. App. 6/4/40.

U. S. PATENT APPLICATIONS VESTED IN ALIEN PROPERTY CUSTODIAN

ELECTRICAL PROSPECTING

U. S. Application serial no. 333,469. O. Martienssen. Filed 5/6/40. Class 175. Vested in Alien Property Custodian.

Method and Means for Determining and Tracing Insulating, in Particular Oil-Carrying Strata. A method of electric transient prospecting in which a repeated aperiodic electric discharge is applied to the ground and the resulting primary and reflected electrical disturbance in the ground observed with a cathode ray oscilloscope having synchronized sweep.

U. S. Application serial no. 410,612. A. Zabelli. Filed 9/12/41. Class 175. Vested in Alien Property Custodian.

Electromagnetic Devices for Researching Sunken Ships, Iron Containing sands and Other Metal Containing Bodies on the Sea Ground. An underwater metal finder consisting of a heavy waterproof housing containing an open core electromagnet which is in one arm of an a-c bridge excited from a vacuum tube oscillator and bridge unbalance detected by a filtered vacuum tube amplifier.

GRAVIMETRIC PROSPECTING

U. S. Application serial no. 377,395. A. Graf. Filed 2/4/41. Class 265. Vested in Alien Property Custodian.

Gravity Meter. A gravity meter of the type in which the moving system carries shutters which affect the amount of light falling on differentially connected photocells, construction permitting adjustment of the moving shutters and minimizing heat transfer to the apparatus from the light sources.

MAGNETIC PROSPECTING

U. S. Application serial no. 402,530. G. Barth. Filed 7/15/41. Class 175. Vested in Alien Property Custodian.

Means for Measuring Magnetic Fields. A magnetic gradiometer having two long bars of high permeability material and measuring their incremental permeability either by a-c or d-c pulses through a coil about each bar and connected in a differential indicator circuit.

SEISMOGRAPH PROSPECTING

U. S. Application serial no. 254,743. R. Maillet. Filed 2/4/39. Class 177. Vested in Alien Property Custodian.

Method and Apparatus for Seismic Underground Prospecting. A seismograph amplifier having its filter frequency controlled as a function of time by driving the rotor of an air condenser in the filter circuit, and having sensitivity controlled as a function of time by mechanically driving a grid bias adjusting rheostat.

[11] Abstracted in GEOPHYSICS, April, 1944.

U. S. Application serial no. 326,567. G. I. Dallos. Filed 3/29/40. Class 178. Vested in Alien Property Custodian.

Amplitude Limiting Circuits. A noise suppression circuit for limiting the peak amplitude of an a-c signal by the use of two tandem connected diodes biased so as to transmit only normal signal amplitudes.

U.S. Application serial no. 387,780. P. H. Dijksterhuis. Filed 4/9/41. Class 177. Vested in Alien Property Custodian.

Device for Converting Variations of a Mechanical Quantity into Variations of an Electric Voltage. A modulated carrier system of measuring displacement in which the demodulated output controls the grid bias of an amplifier tube, so as to compensate for non-linearity in the transducer itself.

U.S. Application serial no. 393,526. W. Moser. Filed 5/15/41. Class 179. Vested in Alien Property Custodian.

Automatic Volume Control Device. An AVC circuit in which amplification is controlled by changing the grid bias of a tube, and having an auxiliary shunting tube whose bias is controlled in the opposite direction, so as to avoid any phase shift in the amplifier due to AVC action.

WELL LOGGING AND SURVEYING

U.S. Application serial no. 271,524. M. Schlumberger. Filed 5/3/39. Class 255. Vested in Alien Property Custodian.

Coring Tool. A hollow side wall coring projectile whose base plate is a separate part, so that when the projectile cuts its core no fluid is trapped behind it.

U.S. Application serial no. 342,488. O. Martienssen. Filed 6/26/40. Class 73. Vested in Alien Property Custodian.

Thermometer for Deep Well Measurements. A resistance thermometer for operation on a single conductor cable with ground return and using as the resistance element a high resistance high temperature coefficient semi-conductor in series with a high voltage battery and milliammeter.

MISCELLANEOUS

U.S. Application serial no. 222,758. H. Neumann and H. Edler. Filed 8/3/38. Class 175. Vested in Alien Property Custodian.

Method of Manufacturing Permanent Magnet Bodies. Making a permanent magnet by assembling a series of wires or sheets of the magnetic material.

U.S. Application serial no. 276,093. M. Schlumberger. Filed 5/27/40. Class 102. Vested in Alien Property Custodian.

Projectile for Perforating Bore Hole Casings. A composite gun perforator projectile made up of a hard steel core and an outer sheath of a soft light material so that higher velocity may be attained and any desired size perforation may be made with the same gun.

U.S. Application serial no. 315,157. M. Schlumberger. Filed 1/23/40. Class 164. Vested in Alien Property Custodian.

Gun Perforator. A gun perforator made up of a number of sections each having three longitudinal cartridge chambers and radial gun bores and three electrical connectors to the adjacent section, firing being electrically accomplished over a single conductor cable and a shock operated selector switch in the top section of the gun.

U.S. Application serial no. 344,790. H. Kietz, M. Schumacher and F. W. Kallmeyer. Filed 7/10/40. Class 177. Vested in Alien Property Custodian.

Device for Directed Reception of Wave Motions. A receiving system for a directional hydrophone having an amplifier with AVC and also a circuit for leveling temporary fluctuations in background noise by means of a rectifier, R-C filter and d-c indicating meter.

U.S. Application serial no. 345,002. K. Nagai and S. Nemura. Filed 7/11/40. Class 178. Vested in Alien Property Custodian.

Filters. A lattice type four terminal filter network in which one cross reactance and one series reactance are replaced by simple resistances.

U.S. Application serial no. 360,689. W. Schrader. Filed 10/10/40. Class 175. Vested in Alien Property Custodian.

Device for Indicating Contaminations in the Oil Circulating System. A device for indicating the presence of metal particles in a lubricating oil which first centrifuges the oil and then detects the presence of conducting particles in the sludge by a change in electrical resistance or capacity.

U.S. Application serial no. 369,882. T. Iseki. Filed 12/12/40. Class 219. Vested in Alien Property Custodian.

Process of Manufacturing a Built-Up Permanent Magnet. Attaching pole pieces to a permanent magnet by spot welding on non-magnetic side plates which have been preheated and when cooled, pull the parts to a tight fit.

U.S. Application serial no. 385,174. W. Barsties. Filed 3/25/41. Class 73. Vested in Alien Property Custodian.

Fluid Level Gauge. An immersion type tank fluid level gauge consisting of a long right angle prism having an extended light source along one base and an extended photocell along the other base, the light being totally reflected at the hypotenuse to the photocell only where not immersed in liquid.

U.S. Application serial no. 391,620. J. L. Snoek and L. Alons. Filed 5/3/41. Class 175. Vested in Alien Property Custodian.

Magnetic System. A method of increasing the efficiency of a magnetic circuit of high flux density which consists in making the non-permanent magnet parts out of a cast ferromagnetic alloy whose cooling is controlled so that columnar crystals grow in the direction the flux is to take, thereby imparting maximum permeability at high flux densities.

PATENTS*

ELECTRICAL PROSPECTING

U.S. No. 2,342,626. H. M. Evjen. Iss. 2/29/44. App. 1/8/42. Assign. Nordel Corp.

Apparatus for Making Geophysical Explorations. An apparatus using commutated d-c for making four electrode earth resistivity measurements, and made direct reading by passing the ground current through the field of a constant speed driven generator whose armature output feeds the potentiometer against which the earth potential is balanced.

U.S. No. 2,342,627. K. H. Evjen and H. M. Evjen. Iss. 2/29/44. App. 1/8/42. Assign. Nordel Corp.

Apparatus for Making Geophysical Explorations. A direct reading apparatus using commutated d-c for making four electrode earth resistivity measurements, and in which a part of the ground current is passed through an interrupter and transformer and rectified, the resulting d-c being used to feed the potentiometer against which the earth potential is balanced.

U.S. No. 2,342,628. H. M. Evjen and W. B. Lewis. Iss. 2/29/44. App. 4/23/42. Assign. Nordel Corp.

Coupling Circuit. A four terminal coupling device for electric measurements, the input being connected to the primary coil of a transformer whose air gap is rapidly varied and the secondary coil output being compensated and rectified so that the output voltage is proportional to the input voltage.

U.S. No. 2,342,629. H. M. Evjen and W. B. Lewis. Iss. 2/29/44. App. 7/1/42. Assign. Nordel Corp.

Coupling Circuit. A coupling device for electrical measurements, the input being connected to a rotating air-cored coil magnetically coupled to a secondary coil whose output is filtered to compensate for voltage changes due to variations in speed of the primary coil.

U.S. No. 2,342,676. W. B. Lewis. Iss. 2/29/44. App. 11/26/41. Assign. Nordel Corp.

Frequency Converter System for Geophysical Prospecting. A circuit for making low frequency square wave earth impedance measurements with four electrodes, using a moderate frequency a-c generator and a low speed commutator to control thyratron rectifiers which feed the ground current, and balancing the ground potential against a rectified potential also obtained from the a-c generator.

GEOCHEMICAL PROSPECTING

U.S. No. 2,338,643. L. Horvitz. Iss. 1/4/44. App. 7/20/42.

Geochemical Prospecting. A method of geochemical prospecting and well logging in which soil samples are first treated with an aqueous solution of a salt of a metal below iron in the electromotive series and then with an inorganic acid to liberate hydrocarbons.

U.S. No. 2,239,651. D. S. Reardon, E. G. Brewster, and R. T. Sanderson. Iss. 1/8/44. App. 2/29/40. Assign. Stanolind Oil and Gas Co.

* Abstracts by O. F. Ritzmann, Gulf Research & Development Company.

Geochemical Prospecting. Apparatus for collecting water-free soil gas samples, consisting of a collector tube sealed into the ground and a series of sections containing sorbents for water, basic gases, acid gases, water again, and finally activated charcoal; flow being induced by thermal convection or a small fan.

U.S.No. 2,343,772. L. Horvitz. Iss. 3/7/44. App. 11/18/39. Assign. E. E. Rosaire.

Geochemical Prospecting. A method of soil analysis prospecting in which the sample is treated to mechanically separate the clay and sand, and only the clay is analyzed for the significant constituent which is expressed per unit quantity of clay.

GRAVIMETRIC PROSPECTING

U.S. No. 2,341,323. J. M. Ide. Iss. 2/8/44. App. 4/21/42. Assign. Shell Development Co.

Gravity Meter. A modified Galitzin type horizontal beam gravity meter in which the hinge support for the beam consists of a leaf spring and in which damping is obtained by immersing the entire instrument in a liquid.

MAGNETIC PROSPECTING

U.S. No. 2,334,393. L. Dillon. Iss. 11/16/43. App. 2/26/40. Assign. Union Oil Company of California.

Determination of Magnetic and Electric Anisotropy of Formation Core Samples. A method of measuring magnetic core anisotropy by placing a cylindrical sample in a coil connected in a heterodyne oscillator circuit and observing the change in beat frequency as the core is rotated.

U.S. No. 2,334,593. R. D. Wyckoff. Iss. 11/16/43. App. 5/8/41. Assign. Gulf Research & Development Co.

Apparatus for Measuring Magnetic Fields. A magnetometer having a bar of high permeability high magnetostrictive material vibrated longitudinally by a piezoelectric oscillator and surrounded by coils which pick up the induced a-c to be amplified and indicated, the bar also being periodically demagnetizod by a second oscillator and the indicator made inoperative during the demagnetizing sequence.

SEISMOGRAPH PROSPECTING

U.S. No. 2,336,053. L. F. Athy and E. V. McCollum. Iss. 12/7/43. App. 3/11/40. Assign. Continental Oil Co.

Method of Making Geophysical Explorations. A plan of reflection seismograph shooting using a number of seismometer spreads or shooting into the same spread from shot holes at varying distances up to the largest at which reflections may be obtained and from the close control thus obtained continuously determining velocity, dip, depth, and divergence.

U.S. No. 2,340,272. M. D. McCarty. Iss. 1/25/44. App. 5/4/40 and 4/30/41. Assign. Socony-Vacuum Oil Co., Inc.

Apparatus for Recording Seismic Waves. A method of obtaining the up-hole impulse on a regular geophone trace by connecting the up-hole detector either in series or parallel with the spread detector and respectively shunting or disconnecting the up-hole detector a short time after the shot is fired by a switch on the shooting machine plunger.

U.S. No. 2,340,275. E. M. Shook and R. W. Olson. Iss. 1/25/44. App. 3/20/40. Assign. Socony-Vacuum Oil Co., Inc.

Method of Seismic Surveying. A method of putting both shot moment and up-hole impulses on a regular geophone trace by using a circuit in which these impulses fire a thyratron thereby blocking subsequent interference.

U.S. No. 2,340,314. F. C. Farnham. Iss. 2/1/44. App. 7/24/43.

Seismic Surveying. A method of seismograph shot loading in which the charge is distributed in a V shaped arrangement pointing away from the detector spread and initiated at the apex, the angle of the V being such that the vector component of explosion propagation velocity is equal to the seismic velocity.

U.S. No. 2,340,770. C. Reichert. Iss. 2/1/44. App. 6/13/40. Assign. Olive S. Petty.

Seismic Recording System. Apparatus for sending irregularly timed radio signals subsequent to the time break to assist in identifying the latter through static, the keying being done by a balance wheel striking a spring mounted contact.

WELL LOGGING AND SURVEYING

U.S. No. 2,330,327. E. Babcock. Iss. 9/28/43. App. 12/17/41. Assign. Halliburton Oil Well Cementing Co.

Pressure Core Taker. A wire line pressure core barrel which is dropped through and latched to the drill stem and having an inverted cup which moves upward as core is cut until it reaches its limit where it closes a lower seal and releases the latch to the drill stem.

U.S. No. 2,334,475. A. Claudet. Iss. 11/16/43. App. 12/4/39 and 12/3/38. Assign. Schlumberger Well Surveying Corp.

Method and Apparatus for Investigating Earth Formation Traversed by Boreholes. A method of well logging in which the walls of the hole are illuminated by light in the ultra-violet to infra-red region, and recording the response of several adjacent photocells with filters to detect fluorescence, phosphorescence and absorption of the incident light.

U.S. No. 2,337,269. R. G. Piety. Iss. 12/21/43. App. 8/14/41. Assign. Phillips Petroleum Co.

Marking Device. A device for firing a radioactive bullet into the walls of a hole while drilling or coring, by having a go-devil or a wire line core barrel make a timed electrical connection to one or more gun barrel units in the drill pipe through contacts on the inside of the pipe.

U.S. No. 2,338,991. J. C. Arnold. Iss. 1/11/44. App. 10/19/40. Assign. Lane-Wells Co.

Magnetic Well Logging. A magnetic well logging apparatus containing two long bars of high permeability material placed end to end with an air gap between them, and recording the flux either on a magnetizable wire run through the gap or by an indicating meter coil with constant current recording photographically.

U.S. No. 2,339,129. M. M. Albertson. Iss. 1/11/44. App. 1/20/42. Assign. Shell Development Co.

Radiological Method of Surveying Wells. A method of radioactive well logging in which a non-radioactive metallic salt and a much smaller amount of radioactive salt of

the same metal is added to the drilling fluid, concentration of the latter in the mud sheath permitting radioactivity logging of the thickness of mud sheath to locate permeable formations.

U.S. No. 2,340,861. C. W. Breukelman. Iss. 2/8/44. App. 8/20/40.

Orienting Device. A device for indicating the low side of a slant hole or the azimuthal orientation of a tool, the device having a ball rolling in an annular insulated track with a contact at a fiducial point, the contact being connected to a hollow insulated sleeve which may be contacted by lowering an electrode on a cable.

U.S. No. 2,340,987. F. T. Robidoux. Iss. 2/8/44. App. 11/14/41. Assign. Halliburton Oil Well Cementing Co.

Electrical Well Caliper. A well calipering device having arms which touch the walls of the hole and whose motion varies the resistance in a d-c circuit connected to a recorder at the surface, and also having a tip switch to indicate a bridge or hole bottom and a-c fired explosive for releasing the caliper arms, the a-c circuit being subsequently available for simultaneously making an electric log.

U.S. No. 2,341,169. R. W. Wilson, A. Long, Jr., and M. T. Randolph. Iss. 2/8/44. App. 12/30/40. Assign. National Lead Co.

Method and Apparatus for Detecting Gas in Well Drilling Fluids. A method of separating gas from a sample of drilling fluid by flowing it through a separating chamber with a viscosity reducing agent and against a counter-current of air and analyzing the gaseous mixture.

U.S. No. 2,341,228. E. E. Moore. Iss. 2/8/44. App. 1/30/42.

Straight Hole Device. A wire line operated inclination recording device which may be used while rotating the drill pipe, consisting of a float in one leg of a U tube containing mercury and a clock driven recording chart which records the oscillation of the float as the drill pipe rotates.

U.S. No. 2,341,745. D. Silverman and R. W. Stuart. Iss. 2/15/44. App. 7/16/40. Assign. Stanolind Oil and Gas Co.

Method for Determining the Nature of Formation Encountered in Well Drilling. A method of mud logging which eliminates delay due to mud return time and in which the mud circulation is reversed for a short time and the logging device run to the bottom through the drill stem on an electric cable.

U.S. No. 2,342,234. W. A. Abegg. Iss. 2/22/44. App. 8/16/43. Assign. Abegg & Reinhold Co., Ltd.

Pipe Measuring Apparatus. A device for measuring pipe lengths when going in or out of the hole, consisting of a horizontal upper telescope for sighting at the top of the pipe and carrying the end of a measuring tape, and a lower telescope near the derrick floor for sighting at the lower end of the pipe and carrying an index for reading the tape.

U.S. No. 2,342,273. J. T. Hayward. Iss. 2/22/44. App. 8/19/40.

Method of Detecting Oil in Well Drilling. A method of mud logging while drilling in which the samples of mud return are treated with a viscosity reducing agent and the petroleum content determined by mechanical separation or by fluorescence, and locating the petroleum bearing formation from the drilling rate and circulation rate.

MISCELLANEOUS

U.S. No. 2,338,732. P. W. Nosker. Iss. 1/11/44. App. 7/9/41.

System for Measuring Force and Acceleration. An accelerometer using magnetostrictive elements mechanically in push pull and connected in an a-c bridge circuit having a d-c meter and vacuum tube rectifiers for an indicator.

U.S. No. 2,338,811. A. F. Hasbrook. Iss. 1/11/44. App. 4/11/41. Assign. Olive S. Petty.

Level Indicator. A remotely indicating level in which the level vial has conductors sealed into it to contact either a conducting liquid with bubble or a drop of mercury, and a selector switch in an electric circuit to permit picking the location of the bubble.

U.S. No. 2,339,274. G. L. Kothny. Iss. 1/18/44. App. 8/10/39. Assign. Sperry-Sun Well Surveying Co.

Electrical Connecting Means for Well Bore Apparatus. A device for making electrical connections to apparatus on the lower end of the drill stem by lowering a multi-conductor cable through the drill stem, the cable having concentric contactors carried on a plug which is guided and latched in place on the apparatus or held in place by fluid pressure.

U.S. No. 2,339,588. D. O. Sproule. Iss. 1/18/44. App. 7/30/36 and 7/22/37. Assign. One-third to A. J. Hughes and one third to Henry Hughes & Son, Ltd.

Echo Sounding Apparatus. An echo sounding indicator having an oscillating bar pivoted at its center, one end of the bar traversing a scale and the other end having a magnetic driving mechanism, the bar carrying inertia operated switches for controlling the sound transmitter and for energizing the driving mechanism.

U.S. No. 2,340,146. A. C. Ruge. Iss. 1/25/44. App. 10/2/41.

Strain Gauge. A bonded filament, resistance type strain gauge made up in groups on a sheet from which one unit may be cut as needed, the units being covered with a thermally insulating felt pad.

U.S. No. 2,340,609. R. Mestas. Iss. 2/1/44. App. 8/3/40. Assign. Kobe, Inc.

Apparatus for Determining Displacements. A device for electrically indicating large longitudinal displacements and having a slightly tapered iron shaft which moves between the poles of transverse iron cored coils, the impedance of the coils being determined in an a-c circuit whose unbalance is detected and amplified by an amplifier which corrects for non-linearity.

U.S. No. 2,341,551. H. Hoover, Jr. Iss. 2/15/44. App. 5/4/40. Assign. Consolidated Engineering Corp.

Mass Spectrometer. A mass spectrometer having several collectors for ions of different mass-charge ratio, each collector feeding an amplifier and recording channel so that a record is obtained of the time variation of the constituents.

U.S. No. 2,341,944. B. A. Olsen. Iss. 2/15/44. App. 3/5/40. Assign. California Cotton Mills Co.

Stemming Wad for Blastholes. A cotton tamping wad which has a fireproof and waterproof coating loaded with heavy metal powder to make the unit sink in water.

U.S. No. 2,342,141. A. Hansen, Jr. Iss. 2/22/44. App. 1/30/42. Assign. General Electric Co.

Force Measurement. A force or displacement transferring or indicating deviee consisting of two concentric cylindrical permanent magnets having axial relative motion and having a damping cylinder in the flux path between them.

U.S. No. 2,342,171. E. E. Turner, Jr. Iss. 2/22/44. App. 1/5/40 and 11/22/40. Assign. Submarine Signal Co.

Apparatus for Echo Distance Measurement. An echo sounding apparatus having a revolving recording stylus which records only during a part of its travel and having a graduated dial for shifting the time zero a known amount off the record, and also having a reflected impulse amplifier which may be set into oscillation to make a reference line on the record.

U.S. No. 2,343,520. L. D. Baver and B. T. Shaw. Iss. 3/7/44. App. 6/12/40. Assign. The Ohio State University.

Method of Measuring Moisture. A method of determining the moisture content of soils by inserting into the soil a small heating coil whose resistance change before and after passage of a heating current is measured with a Wheatstone bridge.

DISCUSSION AND COMMUNICATIONS

In a letter dated May 9, Mr. B. G. Swan, geophysicist with the Continental Oil Company of Ponca City, Oklahoma, submitted for my inspection an index of wells shot for seismic velocity which he had assembled, and suggested that the Society of Exploration Geophysicists might sponsor the preparation of as complete as possible an index of well velocity surveys, and publish this in GEOPHYSICS for the convenience of the industry, and that furthermore this index might be brought up to date at convenient intervals by publication of the locations of the wells shot for velocity since the last publication.

This seemed to me to be an excellent suggestion, and the service might be one of a type which it is quite definitely the function of the Society to perform for its members and the industry. On consulting local members of the Society, executives of oil company geophysical departments and of seismic contracting organizations, I received the opinion that the proposed service also appeared to them to be a proper function of the Society, that it would be of service to the industry, and that excellent cooperation in assembling the information necessary for preparation and maintenance of the index could be anticipated.

Consequently, in accordance with the authority granted the editor by the constitution, I requested Mr. Swan to accept an appointment as Special Velocity Survey Editor, for the purpose of assembling a comprehensive index of well velocity surveys. He has consented to accept this appointment.

Mr. Swan has written to the majority of oil companies which have contracted extensive seismic work in the past, to the oil companies maintaining their own seismic crews, to the seismic service organizations, and to the secretaries of the several cooperative well velocity survey associations, submitting as complete a well velocity survey index as he has been able to assemble without outside help, and requesting that the index be checked, and information concerning wells absent from his list be added. He has requested furthermore, that henceforth when a well has been shot for velocity that the fact be reported to the Editor of GEOPHYSICS, who will at convenient intervals publish this information, in the same manner that information on geophysical patents is published.

It is hoped that the information sought by Mr. Swan will be received promptly, in order to enable the comprehensive well velocity survey index to be published in the October number of GEOPHYSICS..

It is the intention of the Editor to have a sufficient number of reprints of the index prepared to be able to supply a few to any geophysical organization requesting them.

JOSEPH A. SHARPE
Editor

The following letter has been received from Mr. Don R. Knowlton, Director of Production, Petroleum Administration for War. The paper referred to, *Classification of Exploratory Drilling for Petroleum*, has been examined by the members of the Executive Committee, but is not being published in GEOPHYSICS since it is not specifically of interest to geophysicists, and since it has been published as Part II of Frederic H. Lahee's *Exploratory Drilling and Statistics for 1943*, A.A.P.G. Bulletin, Vol. 28, No. 6, pp. 701–21 (June 1944). (EDITOR'S NOTE.)

PETROLEUM ADMINISTRATION FOR WAR
WASHINGTON 25, D. C.

May 29, 1944

Mr. W. H. Taylor, Secretary-Treasurer,
The Society of Exploration Geophysicists,
c/o Petty Geophys. Engineering Company,
San Antonio, Texas

Dear Mr. Taylor:

The enclosed paper, "Classification of Exploratory Drilling for Petroleum," is being forwarded to you and to other geological and geophysical societies throughout the United States in order that you may become familiar with recent steps which have been taken to improve the quality of statistical data compiled on exploratory drilling.

As you undoubtedly know, past and present figures on exploratory well completions differ to such an extent that comparisons are practically impossible. The lack of uniformity in defining and classifying exploratory tests is primarily responsible for such discrepancies.

Dr. F. H. Lahee of the Sun Oil Company, Dallas, Texas, and chairman of the committee on Standardization of Classifications and Definitions of Exploratory Wells of the American Association of Petroleum Geologists, in cooperation with other members of the A. A. P. G. and of the Petroleum Administration for War, has drafted this final report in an effort to bring about uniform classification and usage of terminology.

This Agency urges the adoption of the definitions, classifications, and Table II for use in compiling statistics. With the cooperation of the entire petroleum industry, we anticipate more accurate exploratory figures in the future. Any assistance you may give in bringing these definitions to the attention of your members will be appreciated.

Sincerely yours,
D. R. Knowlton,
Director of Production.

PUBLICATIONS RECEIVED

(The publications listed below were received since issuance of GEOPHYSICS for April, 1944, and are available for loan to the membership. Articles cited are those of particular interest to geophysicists.)

American Journal of Science, Vol. 242, No. 5 (May, 1944), New Haven.
Bulletin of the Academy of Sciences of the Union of Soviet Socialist Republics, Nos. 2, 3, and 5, (1943), Moscow.
Bulletin of the American Association of Petroleum Geologists, Vol. 28, Nos. 4, 5 ("How to Make Velocity Corrections," by John W. Daly), and 6 (April, May, June, 1944), Tulsa.
Geophysical Abstracts, 116 (January-March, 1944), Washington.
Independent Petroleum Association of American Monthly, The, Vol. XV, No. 1, (May, 1944), Tulsa.
Journal of Applied Physics, Vol. 15, Nos. 3, 4 (March, April, 1944), Lancaster.
Journal of the Institute of Petroleum, Vol. 30, No. 243, (March, 1944), London.
Petroleum, Vol. VII, No. 4 (April, 1944), London.

Proceedings of the Cambridge Philosophical Society, Vol. 40, Part 1 (March, 1944), Cambridge.

Publicaciones del Instituto de Fisiografia y Geologia:

XV. *El Estudio de los Cristales en el Espectro Infra-rojo*, by Andres Levialdi, Rosario, Argentina, 1943.

XVI. *Construccion de un Radiometro Diferencial para Espectroscopia en el Infra-rojo*, by Andres Levialdi, Rosario, Argentina, 1943.

XVII. *Estudio Geologico-Economico del Yacimiento de Mineral de Antimonio* (*Estibina*), by Luciano R. Catalano, Rosario, 1943.

XVIII. *El Preensendadense es un Horizonte Geologico o una Facies?*, by Alfredo Castellanos, Rosario, 1943.

XIX. *Geologia Economica del Yacimiento de Plomo, Plata, Oro y Zinc*, by Luciano R. Catalano, Rosario, 1943.

Review of Scientific Instruments, The, Vol. 15, Nos. 3, 4 (March, April, 1944), Lancaster.

Terrestrial Magnetism and Atmospheric Electricity, Vol. 49, No. 1 (March, 1944), Baltimore.

World Petroleum, Vol. 15, Nos. 4, 5 (April, May, 1944), New York.

MEMORIAL

LOVIC PIERCE GARRETT (1880–1943)

LOVIC PIERCE GARRETT, Vice-President of the Gulf Oil Corporation and of the Gulf Refining Company, died on December 13, 1943, at his home in Houston, Texas.

Mr. Garrett was an Honorary Member of the Society of Exploration Geophysicists, and a Past-President of the American Association of Petroleum Geologists.

Mr. Garrett was born in LaGrange, Georgia, on October 27, 1880, and moved to Texas in 1892 and settled in DeLeon, in Comanche County. He graduated from the DeLeon High School and attended the University of Texas from 1899 to 1902 when he accepted a position in the then recently organized Rio Bravo Oil Company, where Dr. E. T. Dumble was in charge of the geological work for this Company and other mineral interests of the Southern Pacific Railroad.

Since the oil fields of greatest interest at that time in Texas were salt domes, it was natural that Mr. Garrett should soon become an outstanding authority on this particular structural feature with which the oil fields were associated. Some of the salt domes had definite indications in the form of topographic highs, oil and gas seepages, and peculiar chemical composition of the shallow waters. Other similar surface anomalies in the Gulf Coast were examined by Mr. Garrett, and shallow wells were drilled on some of them on the theory that they too, represent surface indications of salt domes. Several additional domes were discovered as a result of this campaign, but it was his

thought that there should be many more domes in the region, and in 1924, on his recommendation, geophysical investigations of some of these localities were initiated, both with the torsion balance and with the refraction seismograph. As a result of work done under his direction, a number of additional shallow domes were found, and the campaign was extended to areas where there were no surface shows. This additional prospecting resulted in a further discovery of shallow domes, and in the recognition of geophysical anomalies at greater depths. It was necessary in this first geophysical campaign to plan a program which would develop as much information as possible without undue cost per acre, and under field operating conditions of different kinds such as climate and terrain.

Mr. Garrett's personal familiarity with the entire Gulf Coast district, and with much of the country inland—in North Louisiana and West Texas—enabled him to improve the efficiency of coverage of the crews engaged in this campaign. He was interested in every form of geophysical prospecting just as he was interested in both surface and subsurface geological mapping, and under his direction considerable investigation was made of electrical and other forms of surveys as well as the finally more standardized methods of gravity and seismic prospecting.

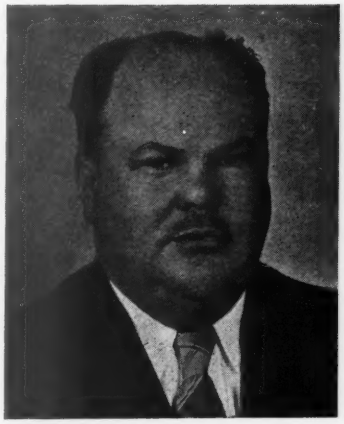
In addition to the direction of this form of exploration, he was concerned with the land and leasing activities and with the production department of the Gulf Companies successively as Chief Geologist and as Vice-President of the Gulf Oil Corporation and Gulf Refining Company. His continuing interest in geophysical methods was recognized by the Society of Exploration Geophysicists in his election as Honorary Member; and he was an assiduous reader of the literature although he himself, in view of his many other interests, did not contribute to this literature.

The outstanding personal traits of Mr. Garrett which contributed so much to the success of the work done under his direction were his patience, his catholicity, and his continual study of the results and of the possible leads which they gave to improve any methods. From the courtesy, kindliness, and patience with which he met the problems of the personnel in the organization, was derived the successful team-work which gave rapid, valuable results to the geophysical work which he conducted. The effectiveness of this work is patent from the number of salt domes and deep structures which were discovered by the Gulf in the campaign in the Gulf Coast as compared with the total of all those found by competing organizations during the same campaign. It is this rapid successful campaign which led to the great expansion of geophysical activity in the petroleum industry. Had this, and work done by similar pioneers in the period from 1924 to 1928, been less efficient, not only would the rate of general discovery have been decreased, but the general recognition of the value of geophysical prospecting in the oil industry would have required much longer time, and many of the fields now in production might not yet have been discovered.

In recent years, Mr. Garrett's interest in new petroleum provinces was manifest by his personal attention to the exploration program in Mississippi, and it is now obvious that this State will justify his early campaign which began some fifteen years ago.

PAUL WEAVER.
Houston, Texas

CONTRIBUTORS



MARK C. MALAMPHY

MARK C. MALAMPHY attended Carnegie Institute of Technology 1920–21 and George Washington University (evening classes) 1921–26, majoring in physics. He worked at the U. S. Bureau of Standards from 1918–1926 (excepting time out for college work) reaching the grade of Assistant Physicist. From 1926 to 1929 was engaged in refraction seismic work in the Gulf Coast for various companies. In September, 1929, he went to Argentina as Chief Geophysicist of the Argentine Government Oil Fields (Y.P.F.) and organized and directed the Comisión Geofísica using the magnetic, torsion balance and seismic refraction methods. From 1932–1936, he was Consulting Geophysicist to the Brazilian Geological Survey and directed magnetic, gravity, seismic and electrical surveys for petroleum and metallic minerals. Returning to the States in 1937, he was engaged as Consulting Geophysicist by the Haile Gold Mines, Inc., of Kershaw, S. C. and New York City. In 1938, he became associated with Hans Lundberg, Ltd. of Toronto, Canada and had charge of numerous geophysical surveys for metallic minerals in Canada, Cuba, Ecuador and various parts of the United States. In July of 1941 he joined the staff of the Bureau of Mines as Consulting Physicist and in December of the same year accepted an appointment as Senior Technologist and was given charge of the Bureau of Mines program of prospecting for bauxite in Arkansas. He is a member of the American Institute of Mining and Metallurgical Engineers, American Association of Petroleum Geologists, Society of Exploration Geophysicists, American Geophysical Union and Brazilian Institute of Mining and Metallurgy.

JAMES L. VALLELY

JAMES L. VALLELY received his B.S. degree in Mining Engineering from the University of Notre Dame in 1927. From 1927 until 1932 he was employed by Consolidated Coppermines Corporation at Kimberly, Nevada, as a Mining Engineer, and from 1933 to 1937 was Project Engineer for the Penna. Dept. of Forests & Waters and U. S. Forest Service. In 1937 he returned to Consolidated Coppermines Corporation as Assistant Chief Engineer, remaining there until 1942. Since 1942 he has been with the U. S. Bureau of Mines as an Associate Mining Engineer, assigned to the Arkansas Bauxite Project.

R. MAURICE TRIPP

R. MAURICE TRIPP received a degree of Geological Engineer in 1939, a Master of Geophysical Engineering in 1943, and is currently completing work for a Doctor of Engineering in Geophysics, all at the Colorado School of Mines. During half of 1936 and 1937 he was associated with the Geotechnical Corporation engaged in seismic work in the field and laboratory. He returned to the Geotechnical Corporation following the completion of academic work in 1939 and remained until 1941 when he returned to Colorado Mines to do graduate research and teaching in geophysics and geology. His major field of research has been in geochemical and radioactive studies as related to prospecting. Considerable attention has also been directed toward consulting work in metallic mineral exploration by geophysics. Mr. Tripp is a member of the American Institute of Mining and Metallurgical Engineers, the American Association of Petroleum Geologists, Society of Exploration Geophysicists, Tau Beta Pi, and Sigma Gamma Epsilon.

Photographs and biographies of contributors to this issue not appearing above have been published previously, as follows: RALPH D. WYCKOFF, Vol. VIII, No. 1, p. 76 (Jan. 1943); H. B. PEACOCK, Vol. VII, No. 3, p. 328 (July 1942); NORMAN RICKER, Vol. VI, No. 3, p. 254 (July 1941); O. F. RITZMANN, Vol. VII, No. 4, p. 428, (Oct. 1942).

THE SOCIETY ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following candidates for membership in the Society. This publication does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it to the Secretary within thirty days. (Names of sponsors are placed beneath the name of each nominee.)

ACTIVE

John Allen Cathey
H. B. Peacock, Cecil H. Green, Phil P. Gaby

Ralph Charles Cole
Karl Dyk, M. B. Widess, Neil R. Sparks

Charles Ethan Duller
W. G. Green, Hart Brown, J. Neufeld

James Everitt
Cecil H. Green, Phil P. Gaby, Francis A. Hale

Robert Earl Fearon
E. H. Cooley, C. E. Buffum, Joseph A. Sharpe

Willis H. Fenwick
Hart Brown, C. A. Heiland, C. Sheldon Sharp

John Edward Futral
Louis A. Scholl, Jr., Roy L. Lay, George D. Mitchell, Jr.

Nancy Morgan Hilger
Cecil H. Green, M. C. Kelsey, E. J. Stulken

Murrell Holbert
Cecil H. Green, M. C. Kelsey, Floyd J. Williams

Leland Willard Jones
Chester F. Barnes, John P. Lukens, Jess Vernon

Joseph Rashid Jubran
Cecil H. Green, M. C. Kelsey, E. J. Stulken

Gustave John Kohler
Cecil H. Green, E. J. Stulken, M. C. Kelsey

Carlton M. Marquardt
(Article III-D-1 of the Society Constitution)

Edwin Lawrence Miller, Jr.
(Article III-D-1 of the Society Constitution)

Phillip Herschel Mintz
T. I. Harkins, R. S. Jackson, A. D. Dunlap

Frederick Asa Moore
M. C. Kelsey, E. J. Stulken, Floyd J. Williams

Robert Roy Moore
Cecil H. Green, E. J. Stulken, Floyd J. Williams

Robert Trudeau Penny
N. N. Zirbel, T. I. Harkins, A. L. Smith

Jack Warren Peters
Henry C. Cortes, Paul E. Nash, Cornelius G. Dahm

Harold Daniel Petre
Hart Brown, C. Sheldon Sharp, Robert L. Kidd
William Bryan Raper
Henry C. Cortes, Paul E. Nash, J. C. Menefee
Florence Robertson
James B. Macelwane, S. J., Stanley W. Wilcox, Albert J. Barthelmes
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T. A. Manhart, G. H. Westby, Albert J. Barthelmes
Joy Scamman
H. B. Peacock, Cecil H. Green, Phil P. Gaby
Carlyle George Schauble
F. B. Leedy, Albert J. Barthelmes, H. M. Thralls
Delbert Franklin Smith
Stanley W. Wilcox, H. M. Thralls, Albert J. Barthelmes
Russell D. Terry
Phil P. Gaby, H. B. Peacock, Cecil H. Green

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Karl Koehn Kundert
Stefan Von Croy, Albert J. Barthelmes, Worth B. Hurt
Theo Virginia Murray
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Eli Marion Raines
T. I. Harkins, R. S. Jackson, C. R. Lowe
Thomas John Thomas
H. Klaus, Stefan Von Croy, W. K. Hastings
Lloyd Morris Urban
Harold H. Jones, R. S. Jackson, H. M. Falkenhagen
Joseph Leonard Davidson
J. E. LaRue, J. P. Carlton, M. M. Slotnick

STUDENT

Albert Wayne Musgrave
R. Maurice Tripp

THE FOURTEENTH ANNUAL MEETING OF THE SOCIETY OF EXPLORATION GEOPHYSICISTS, BAKER HOTEL, DALLAS, TEXAS, MARCH 21–23, 1944

The Fourteenth Annual Meeting of the Society of Exploration Geophysicists was held at the Baker Hotel in Dallas, Texas, March 21–23, 1944. The Annual Meetings of the American Association of Petroleum Geologists and the Society of Economic

Paleontologists and Mineralogists were held concurrently. Because of the central location selected for the joint meetings, attendance was exceptional, there being some 1350 registrants. S. E. G. members registered as being in attendance and listed immediately following this résumé totaled 246.

The Society of Exploration Geophysicists convened for technical sessions Tuesday, March 21, a day ahead of the A.A.P.G., in order that joint meetings might be held Wednesday and Thursday, the two days devoted to papers of general interest. Only two technical sessions, featuring a total of twenty papers presented or given by title, were held. The first of these began immediately after the Annual Business Meeting, at which results of the balloting for officers were announced. These sessions, as well as those held jointly with the A.A.P.G. and S.E.P.M., were in the Baker Hotel's Crystal Ball Room, which was at times filled to overflowing.

Because of limitations on time and space, the usual Society luncheon was omitted. Similarly, because of the serious nature of the meeting, no attempts at organized entertainment were made. Technical papers occupied the evenings of the 21st and 22nd. The first evening featured A. I. Levorsen's annual "Survey of Geology Students" and a paper by Roland F. Beers on "Radioactivity and Organic Content of Some Paleozoic Shales." On the evening of the 22nd, T. S. Oakwood discussed "The Role of Chemistry in the Origin of Oil."

Thanks are due the Program and Arrangements Committee, composed of E. D. Alcock, John H. Wilson, L. L. Nettleton, Raymond A. Peterson, Dart Wantland, and Norman Ricker, and under the Chairmanship of Cecil H. Green, for the excellent program of papers secured for the Society's technical sessions. Titles of these papers are presented elsewhere in this number of GEOPHYSICS. Although a strong program was secured for the meeting, considering wartime conditions, additional papers are still required to ensure the issuance of four full quarterly issues of the Society journal, and these are respectfully solicited. Members who were unable to complete papers in time for presentation at the Fourteenth Annual Meeting are requested to write Joseph A. Sharpe, Editor of GEOPHYSICS, P.O. Box 591, Tulsa 2, Oklahoma, regarding publication.

MEMBERS REGISTERED AT THE FOURTEENTH ANNUAL MEETING

Joseph L. Adler
Flint H. Agee
E. D. Alcock
R. D. Arnett
Kingsland Arnold
R. L. Augenthaler
Glenn E. Bader
Robert Barling
A. J. Barthelmes
C. B. Bazzoni
A. F. Beck
Roland F. Beers
Roy F. Bennett
G. A. Berg
Thomas J. Bevan
John L. Bible
L. W. Blau
F. H. Borman
W. T. Born
D. F. Broussard
Hal Brown
Hart Brown
L. I. Brown
Harry M. Buchner
C. E. Buffum
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W. W. Butler
D. B. Campbell
Francis F. Campbell
D. P. Carlton
E. L. Caster
C. E. Chesher
V. E. Child
R. E. Clark
Neal Clayton
D. H. Clewell
Howard L. Cobb
R. Clare Coffin
D. M. Collingwood
J. R. Cornett
Henry C. Cortes
Ira H. Cram

C. G. Dahm
John W. Daly
Nathan C. Davies
Donald M. Davis
E. DeGolyer
E. L. Deloach
Alexander Deussen
D. C. DeWoody
C. Hewitt Dix
D. Ray Dobyns
John Doering
Chester J. Donnally
Karl Dyk
J. Brian Eby
L. G. Ellis
T. P. Ellsworth
Vincent Emanuel
H. M. Falkenhagen
Paul Farren
B. D. Farrow
V. G. Feather
John L. Ferguson
Craig Ferris
Robert S. Finn
L. I. Freeman
Ewin D. Gaby
Phil P. Gaby
J. F. Gallie
R. W. Gemmer
J. R. Gilliland
John A. Gillin
Andrew Gilmour
F. Goldstone
Cecil H. Green
W. G. Green
T. O. Hall
A. B. Hamil
Willis W. Hardy
T. I. Harkins
Bruce H. Harlton
Sidon Harris
J. E. Hawkins
C. A. Heiland
Walter E. Heinrichs, Jr.
William B. Heroy
H. F. Hieatt
J. O. Hoard
John C. Hoffman
Malvin G. Hoffman
W. B. Hogg
W. E. Hollingsworth
Herbert Hoover, Jr.
Leo Horvitz
B. Hubbard
Joe B. Hudson
D. S. Hughes
John F. Imle
Arland I. Innes
Howard Itten
Frank Ittner
John S. Ivy
R. S. Jackson
J. E. Jett
Curtis H. Johnson
James F. Johnson
J. C. Karcher
W. W. Kelley
M. C. Kelsey
Graham D. Kendall
R. B. Kerbow
Robert L. Kidd
Carl L. Larson, Jr.
O. T. Lawhorn
Roy L. Lay
W. B. Lee
E. G. Leonardon
John A. Lester
Wm. Bradley Lewis
J. B. Lovejoy
Paul L. Lyons
James B. Macelwane, S.J.
Lewis W. MacNaughton
Mark C. Malamphy
O. B. Manes
John D. Marr
Phil F. Martyn
Tom D. Mayes
C. G. McBurney
M. M. McCaleb
E. V. McCollum
H. W. McDonnold
George C. McGhee
Glenn M. McGuckin
R. L. McLaren
J. B. Meitzen
J. C. Menefee
Vincent J. Mercier
Nash H. Miller
Vincent Miller
J. P. Minton
Arthur A. Moore, Jr.
James A. Moore
Charles M. Moore, Jr.
James L. Morris
Matthew T. Murray
P. E. Narvarte
Paul E. Nash
L. L. Nettleton
Jacob Neufeld
Leonard J. Neuman
W. W. Newton
E. T. Nichols
Walter J. Osterhoudt
J. E. Owen
John F. Partridge, Jr.
H. G. Patrick
H. B. Peacock
H. H. Pentz
J. H. Pernell
J. D. Perryman
E. A. Pielemeier
C. V. A. Pittman
Jack C. Pollard
R. B. Pratt
W. R. Ransone
Robert H. Ray
Edward C. Reagor
Cecil E. Reel
Darwin S. Renner
Norman Ricker
Homer E. Roberts
K. A. Robertson
Antonio Garcia Rojas
F. W. Rolshausen
Frederick Romberg
H. W. Rose
Allen M. Rugg, Jr.
W. M. Rust, Jr.
R. B. Rutledge
Henry Salvatori
C. W. Sanders
Sidney Schafer
Edw. G. Schempf
Louis A. Scholl, Jr.

J. P. Schumacher
O. A. Seager
T. O. Seaman
Wesley H. Seifert
George E. Seiler
A. L. Selig
W. A. Seyffert
Nevin R. Shade
C. S. Sharp
Joseph A. Sharpe
E. S. Sherar
T. R. Shugart
W. B. Sibley
Daniel Silverman
M. M. Slotnick
A. L. Smith
Neil R. Sparks
Noel H. Stearn
Booth Strange
E. F. Stratton
E. J. Stulken
Garvin L. Taylor
W. Harlan Taylor
Earl Thomas
J. W. Thomas
A. H. Thompson
Erik Thomsen
Harry L. Thomsen
H. M. Thralls
R. Maurice Tripp
R. H. Tucker
R. F. Van Cleave
Stefan Van Croy
S. K. Van Steenbergh
Jess Vernon
Geo. E. Wagoner
M. J. Walczak
J. E. Walker
Dean Walling
T. N. Walsh
R. F. Weichert, Jr.
R. A. Weingartner
Thomas S. West
G. H. Westby
Rex H. White
Herman F. Whiton
Stanley W. Wilcox
Floyd J. Williams
P. S. Williams
Richard Williams
S. H. Williston
R. M. Wilson
Niles B. Winter
Alexander Wolf
William C. Woolley
John R. Woolson
R. D. Wyckoff
Basil B. Zavoico
Charles C. Zimmerman

PAPERS PRESENTED OR READ BY TITLE AT THE TECHNICAL SESSIONS OF THE FOURTEENTH ANNUAL MEETING

The following titles are of those papers of particular interest to geophysicists, which will be published in GEOPHYSICS during the coming twelve months. Titles of papers given before joint sessions of the S.E.G., A.A.P.G., and S.E.P.M. are not included.

1. NASH H. MILLER, United Geophysical Company, Pasadena, California
   Notes on Well Shooting Data

2. J. A. GILLIN, R. D. ARNETT, and E. D. ALCOCK, National Geophysical Company, Dallas, Texas
   The Correlation Refraction Method of Seismic Surveying

3. PHIL P. GABY, Geophysical Service, Inc., Fresno, California
   A New Type of Seismic Cross Section Wherein Accuracy of Representation Is Rendered Insensitive to Velocity Error

4. PAUL H. BOOTS, Gulf Research & Development Company, Pittsburgh, Pennsylvania
   A Geophysical Survey of Kuwait, Persian Gulf

5. C. HEWITT DIX, United Geophysical Company, Pasadena, California
   The Interpretation of Well Shot Data

6. MONROE W. KRIEGEL, The Carter Oil Company, Tulsa, Oklahoma
   Analysis for Hydrocarbons in the Presence of Nitrous Oxide

7. NORMAN RICKER, The Carter Oil Company, Tulsa, Oklahoma
The Computation of Output Disturbances from Amplifiers for True Wavelet Inputs

8. ALFRED WOLF, Geophysical Research Corporation, Tulsa, Oklahoma
Motion of a Rigid Sphere in an Acoustic Wave Field

9. SIGMUND HAMMER, L. L. NETTLETON, and W. K. HASTINGS, Gulf Research & Development Company, Pittsburgh, Pennsylvania
Gravimeter Prospecting for Chromite in Cuba

10. J. C. BARCKLOW, Lane-Wells Company, Oklahoma City, Oklahoma
Scope and Utilization of Radioactivity Logs

11. GLENN M. MCGUCKIN, Magnolia Petroleum Company, Dallas, Texas
History of the Geophysical Exploration of the Cameron Meadows Dome, Cameron Parish, Louisiana

12. ROBERT E. SOUTHER, Baroid Sales Division, National Lead Company, Tulsa, Oklahoma
Application of Fluid Logging

13. H. B. PEACOCK, Geophysical Service, Inc., Houston, Texas
The Geophysical History of the Cayuga Field, Anderson County, Texas

14. R. MAURICE TRIPP, Colorado School of Mines, Golden, Colorado
Radon Survey of the Fort Collins Anticline

15. SIGMUND HAMMER, Gulf Research & Development Company, Pittsburgh, Pennsylvania
Estimating Ore Masses in Gravity Prospecting

16. JOHN SLOAT, Union Oil Company of California, Bakersfield, California
How Not *to Find an Oil Field*

17. D. T. SECOR, United Natural Gas Company, Oil City, Pennsylvania
Résumé of Reflection Seismograph Results in Northern Oriskany Gas Fields

18. E. J. STULKEN, Geophysical Service, Inc., Dallas, Texas
Effect of Ray Curvature upon Seismic Interpretations

19. HENRY SALVATORI, Western Geophysical Company, Los Angeles, California

Early Reflection Seismograph Exploration in California

20. MARK C. MALAMPHY AND JAMES L. VALLELY, U. S. Department of the Interior, Bureau of Mines, Little Rock, Arkansas

Geophysical Survey of the Arkansas Bauxite Region

21. R. D. WYCKOFF, Gulf Research and Development Company, Pittsburgh, Pennsylvania

Geophysics Looks Forward (Presidential Address)

MINUTES
of the
ANNUAL BUSINESS MEETING OF THE SOCIETY OF EXPLORATION GEOPHYSICISTS HELD IN THE CRYSTAL BALL ROOM, BAKER HOTEL, DALLAS, TEXAS, MARCH 21, 1944

The Annual Business Meeting of the Society of Exploration Geophysicists was held in the Crystal Ball Room of the Baker Hotel in Dallas, Texas. The meeting was presided over by President R. D. Wyckoff and was called to order at 9:40 a.m.

The Secretary-Treasurer's financial report (presented in detail elsewhere in this issue of GEOPHYSICS) was read and accepted.

A membership report, showing 814 active, 173 associate, 11 student, and 3 honorary, or a total of 1001 members, was also presented.

The Editor's report was then read and accepted, following which President Wyckoff read the election results. In counting the ballots, 29 were disqualified, 27 as being from members in arrears and 2 bearing illegible signatures. Officers elected for 1944–45 were announced to be:

W. M. RUST, JR., *President*
HENRY C. CORTES, *Vice-President*
W. HARLAN TAYLOR, *Secretary-Treasurer*

President Wyckoff brought up the question of amending the Constitution so that the Editor would serve two years instead of three. It was moved by Brad Lewis and seconded by Roland Beers that a properly worded amendment be submitted to the membership for approval by ballot. The motion was carried unanimously.

President Wyckoff then took occasion to express the appreciation of the Society to Mr. Cecil H. Green and his Program and Arrangements Committee for their excellent work in connection with the Fourteenth Annual Meeting.

There being no further business, the meeting was adjourned.

Respectfully submitted,

HART BROWN
Secretary-Treasurer

OFFICERS FOR THE YEAR ENDING APRIL 1945

RALPH D. WYCKOFF, Past-President

HENRY C. CORTES, Vice-President

W. M. RUST, JR., President

W. HARLAM TAYLOR, Secretary-Treasurer

JOSEPH A. SHARPE, Editor

BALLOT ON EDITOR'S TERM OF OFFICE

In accordance with the decision reached at the Annual Meeting, the ballot reprinted below was mailed to all active Society members on April 20, 1944.

BALLOT

To the Active Members of
The Society of Exploration Geophysicists:

The resolutions of the Executive and Business Committees printed below received favorable action at the general Business Meeting of the Society in Dallas, Texas, on March 21, 1944 and are now submitted to the membership for final action, as required by the Constitution. Mark the ballot at once and return it in the envelope provided. Sign your name on the envelope but not on the ballot. Your vote must be in the office of the Secretary-Treasurer within ninety days from the date it is mailed to you in order to be counted.

Resolution of the Executive Committee, March 20, 1944

Resolved: That the third sentence in Section V-A-1 of the Society Constitution be amended from "Officers shall be elected for a term of one year with the exception of the Editor, who shall be elected for a term of three years" to "Officers shall be elected for a term of one year with the exception of the Editor, who shall be elected for a term of two years."

Be it further resolved: That the legality of the proposed amendment be and hereby is approved.

Resolution of the Business Committee, March 20, 1944

Resolved: That the Business Committee hereby approves the amendment to Section V-A-1 of the Constitution proposed by Resolution of the Executive Committee, March 20, 1944, and further, be it

Resolved: That the Business Committee hereby recommends to the Society the adoption of said amendment.

DO YOU APPROVE THE PROPOSED AMENDMENT TO THE CONSTITUTION AS SET FORTH IN THE ABOVE RESOLUTION?

YES ☐

NO ☐

ANNUAL REPORT OF THE SECRETARY-TREASURER OF THE SOCIETY OF EXPLORATION GEOPHYSICISTS

The financial condition of the Society of Exploration Geophysicists as of December 31, 1943, is given in the following brief report, reproduced from the annual audit. In addition to the assets noted, nearly 7,000 back numbers of the Society Journal, GEOPHYSICS, were on hand, with a minimum value of $1 each (the cost to members).

Balance Sheet
Society of Exploration Geophysicists—Houston, Texas
December 31, 1943

ASSETS

Current			
Cash			
In Banks		$10,692.76	
Accounts Receivable			
Membership Dues	$357.50		
Advertising	113.50		
Reprints	97.57		
Back Numbers	69.60		
Other	16.10	654.27	$11,347.03
Investment			
Farm and Home Savings and Loan Association of Missouri—Fully Paid Certificate		$ 5,000.00	
U. S. Savings Bonds "Series G" Due 6-1-54		2,000.00	7,000.00
Office Equipment			
Cost		$ 101.17	
Less: Allowance for Depreciation		33.63	67.54
			$18,414.57

LIABILITIES

Current		
Accounts Payable		
For Expenses, Etc		$ 207.82
Deferred Income		
Prepaid Dues and Subscriptions		378.58
Surplus		
Balance January 1, 1943	$14,666.91	
Add		
Increase from Current Year Operations—Per Statement of Income and Expense	3,161.26	17,828.17
		$18,414.57

Income and Expense
Society of Exploration Geophysicists—Houston, Texas
Year Ended December 31, 1943

INCOME

Membership Dues		$4,947.50	
Publications:			
Advertising	$2,541.00		
Subscriptions	1,138.60		
Back Numbers	773.20		
Reprints	191.38	4,644.18	
Other Income:			
Interest Received	$ 277.18		
Commissions on Publications	6.60	283.78	$9,875.46
Less: Discounts to Colleges, etc. on Subscriptions and Back Numbers		220.80	$9,654.66

COSTS AND EXPENSES

Publication Costs:				
GEOPHYSICS:				
Vol. VIII, No. 1—118 pages...	$ 752.95			
No. 2—172 pages...	910.03			
No. 3—128 pages...	618.52			
No. 4—140 pages...	895.25	$3,176.75		
Reprints		289.17	$3,465.92	
Expenses—Per detail schedule			3,027.48	$6,493.40
Excess of Income over Costs and Expenses				$3,161.26

EXPENSES

Salary—Business Manager			$1,200.00
Commissions:			
Advertising:			
Business Manager	$ 260.25		
Agencies	311.97		
Subscriptions, etc.—Agencies	35.60		607.82
Bad Debts			270.20
Stationery and Office Supplies			264.22
Postage and P.O. Box Rent			229.49
Annual Meeting Expense:			
Traveling and Other Expenses—			
Business Manager	$ 209.55		
Printing, etc.	7.71		217.26
Auditing			108.00
Telephone and Telegraph			81.39
Bond Premium			15.00
Society Card—A.A.P.G.			15.00
Depreciation			10.12
Freight and Express			5.47
Bank Charges			3.51
			$3,027.48

Respectfully submitted,
HART BROWN, *Secretary-Treasurer*

PERSONAL ITEMS

(Items for inclusion herein should be addressed to the Society at P. O. Box 410, El Dorado, Arkansas.)

MILTON B. DOBRIN, Physicist with the Naval Ordnance Laboratory in Washington and formerly associated with the Gulf Research and Development Company in Pittsburgh, has established an ESMWT course in Geophysics in the District of Columbia. Appreciable interest has been manifested, and some thirty men, largely employed in war-time government agencies, are enrolled. Thus far MALVIN G. HOFFMAN, A. G. MCNISH, and L. L. NETTLETON (whose text, *Geophysical Prospecting for Oil*, is being used) have been heard as guest speakers.

E. W. JOHNSON, with the Cities Service Oil Co., has been transferred from Chickasha, Oklahoma, to Kingman, Kansas, where his postal address is Box 307.

M. M. MCCALEB, Gravity Supervisor with Humble, is now located in St. Petersburg, Florida, with the mailing address P. O. Box 264.

JOHN C. HOFFMAN, Geophysicist with the United Geophysical Co., is located at 804 Thompson Bldg., Tulsa 3, Okla.

BASIL B. ZAVOICO, who has been serving in the Petroleum Administration for War since leaving the Chase National Bank, has resigned to open consulting offices in New York City. His address is 220 East 42nd St., New York 17, N. Y.

H. C. REICHERT is Geologist for the Gulf Refining Co. in Opelousas, La., with the postal address given as P. O. Box 667.

ROY L. LAY has advised the Society that he was advanced, in the latter part of 1943, to the rank of Assistant Chief of the Geophysical Division of the Texas Co. His address remains P. O. Box 2332, Houston 1, Texas.

FRANCIS A. ROBERTS, of the Carter Oil Co., has been transferred from Worland, Wyoming, to Moose Jaw, Saskatchewan, Canada, where his mailing address is P. O. Box 300.

R. H. DANA, of the Stanolind Oil and Gas Co., has been transferred from Odessa to Big Spring, Texas, with the postal address Box 1592.

DON C. SHORT is employed by the United Geophysical Co., S. A., in Caracas, Venezuela. The postal address is Aptdo. 1085.

B. O. WINKLER, from whom we had not heard in the past two years, has notified the Society that he is now working with Socony-Vacuum Oil Co. de Colombia, Calle 14, No. 8-22, Aptdo. Nac. 1140, Bogota, Colombia, S. A.

The Press Division of the Embassy of the U. S. S. R. has advised the Society that June 5–12 the Moscow University held a scientific conference on the "Role of the Russian Science in the Development of World Science and Culture." Unfortunately the news reached the Society too late to permit transmittal of a message from the Executive Committee.

NATHAN C. DAVIES is Manager of Exploration for the Illinois firm of Bell Brothers, with offices at 307 East Main, Robinson, Ill.

K. R. WEATHERBURN has been transferred from the Shell Co. of Australia to Shell's Geophysical Laboratory, 3705 Bellaire Blvd., Houston, Texas.

S. H. WILLISTON, Vice-President of Horse Heaven Mines, Inc., and the Cordero Mining Co., has announced the opening of a main office at 702-3-4 Mechanics' Institute Bldg., 57 Post St., San Francisco 4, Calif. Mr. Williston may be reached at this address, where he is moving from Portland, Oregon. The Portland office, meanwhile is being moved from 909 Studio Bldg., to 1105 Public Service Bldg., Portland 4.

A. B. WOOD is employed by the Caribbean Petroleum Co., Aptdo. 809, Caracas, Venezuela, S. A.

R. G. SOHLBERG has accepted a position as Geophysicist with South Mediterranean Oilfields, Ltd., 43 Sharia Kasr el Nil, Cairo, Egypt.

JOHN J. JAKOSKY, Director of Industrial Research at the University of Southern California, is located at 1063 Galyey Ave., Los Angeles 24, Calif.

CHESLEY B. PICKLE has returned to the Standard Oil Co. of New Jersey from the Naval Ordnance Laboratory in Washington, D. C. He may be addressed in care of Mrs. W. S. Dudley, 5120 6th St., Port Arthur, Texas.

WILLIAM E. WALLIS is leaving the Standard Oil Co. of Cuba to accept a position as Chief Geologist for the Standard Oil Co. of Egypt in Cairo, Egypt.

CHARLES L. HEALD, STEWART C. PALMERSTON, and DON C. SHORT, all of the United Geophysical Co., have recently been advanced to the rank of Party Chief.

OLAF FRANCIS SUNDT should be addressed henceforth in care of the United States Embassy, Lima, Peru, S. A.

J. B. SOUTHER has returned to San Antonio, Texas, from Lincoln, Nebraska, and is located at 239 Luther Drive, San Antonio 1.

FRANCIS H. CADY, of the Carter Oil Co., is located at Billings, Montana, with the postal address P. O. Box 2104.

V. E. CHILD, with the Texas Co., has been transferred from Hamlin, Texas, to Craig, Colorado. He may be addressed in care of General Delivery in Craig.

A. P. CRARY, engaged in exploration work in England for the past year and a half, is now employed by the United Geophysical Co., S. A., Aptdo. 1085, Caracas, Venezuela.

RICHARD DAVIES has notified the Society of his change of address from the D'Arcy Exploration Co., Southwell Notts, England, to the Geological Dept., Anglo-Iranian Oil Co., Ltd., Britannic House, Finsbury Circus, London, E. C. 2, England.

O. B. MANES is Seismologist with the Shell Oil Co., Inc. He may be reached at 2101 Banks St., Houston 6, Texas.

DARWIN S. RENNER is Superintendent of GSI's Electronics Laboratory, and may be addressed at P. O. Box 2793, Dallas 1, Texas.

The most recent address received from G. E. SCHULTIS, of the Carter Oil Co., is P. O. Box 43, Worland, Wyoming.

Major EDWIN H. ROBINSON, U. S. Army Corps of Enginners, who was recently elected to membership in the Society, should be addressed c/o Mrs. W. K. Young, 2108 Smith St., Houston, Texas.

H. L. SCHIFLETT, of the Texas Co., has been more than usually favored this past year. Having summered in Canada on a gravimeter survey, he then wintered in Florida. His postal address is Box 698, Leesburg.

W. OBIER MARTIN is serving as a Corporal in the 242nd Infantry, at Camp Gruber, Oklahoma. All mail, however, should be addressed to him at P. O. Box 332, McComb, Miss.

VINCENT J. MERCIER has been transferred from Great Bend to Pratt, Kansas, where he is located at 215 N. Ninnescah.

WILTON W. LA RUE has resigned his position as Physicist with the Naval Ordnance Laboratory, Washington, D. C., and is now in charge of geophysical operations for the Plymouth Oil Co., Sinton, Texas.

EDWIN L. FETZER, who has been serving as First Lieutenant, U. S. Army Corps of Military Police, has been placed on the inactive list and relieved from duty. He has resumed his duties with the National Geophysical Co., where he is serving as Party Chief, and is at present located at P. O. Box 251, St. John, Kansas.

DONALD R. BROWN, who has been serving in the Australian Army for the past two years, is returning to the United States to resume his position with the Shell Oil Co., Inc., Box 2099, Houston, Texas.

LT. HARRIS COX may be addressed at COMSO PAC Staff, Fleet Post Office, San Francisco, Calif.

EUGENE WIANCKO, Chief Computer with the United Geophysical Co., lists his address as 2163 Santa Rosa, Altadena, Calif.

CHESTER J. DONNALLY, of the Western Geophysical Co., has transferred his office from Houston to Dallas, Texas, at 1102 First National Bank Bldg.

W. C. MERRITT is Geophysicist with the Exploration Dept., Creole Petroleum Corp., Aptdo. 889, Caracas, Venezuela, S. A.

JAMES G. JACKSON, JR., has returned from Chile to accept a position as Party Chief with the Miller Geophysical Co., and is temporarily located in Orla, Texas.

Lt. (jg) GEORGE C. MCGHEE has returned to Dallas from Fort Worth, Texas, and may again be addressed at 4429 Livingston St.

ERIK THOMSEN, of the Stanolind Oil and Gas Co., has been transferred from Tulsa, Oklahoma, to Fort Worth, Texas, where he may be addressed at P. O. Box 1410.

E. H. VALLAT, formerly with the Continental Oil Co., has accepted a position as Geologist with the Ohio Oil Co. He is located at 429 N. Formosa Ave., Los Angeles 36, Calif.

DWIGHT E. WARD is located at 3004 10th St., Boulder, Colo.

S. K. VAN STEENBERGH, of the Sinclair Prairie Oil Co., is located at 901 Fair Bldg., Fort Worth 2, Texas.

O. T. LAWHORN is with Geophysical Service, Inc., at 1311 Republic Bank Bldg., Dallas 1, Texas.

JAMES A. BROOKS, JR., has been placed on inactive duty and has resumed his position with the Humble Oil and Refining Co., P. O. Box 2180, Houston, Texas.

Lt. ELLIOTT SWEET is Officer-in-Charge, Boston Magnetic Ranges, Castle Island, South Boston 27, Mass.

S. WILLIAM SCHOELLHORN, of Seismograph Service Corp., is now located in Caracas, Venezuela, S. A., where his postal address is Aptdo. 1488.

SAM ZIMMERMAN, Party Chief for the Carter Oil Co., is currently located in Douglas, Wyoming.

C. E. WILLIAMS has returned from South America and is Recorder for the Texas Co., temporarily located at P. O. Box 272, Brewton, Alabama.

R. L. SARGENT, formerly with the National Geophysical Co., has accepted a position with the Apache Exploration Co., Houston, Texas.

C. W. SANDERS, formerly with the Shell Oil Co., Inc., has joined the staff of the Danciger Oil and Refining Co. as Chief Geologist. His address is 2413 Colonial Parkway, Fort Worth 4, Texas.

HENRY L. RASÉ, JR., has been transferred from the Western Gulf Oil Co., Bakersfield, Calif., to the Gulf Research and Development Co., and may be addressed at P. O. Drawer 2038, Pittsburgh 30, Pa.

Corporal LOUIS C. PAKISER, JR., 37343719, may be reached through APO 572, c/o Postmaster, New York, N. Y.

Lt. Col. JOHN V. LONG gives his mailing address as APO 706, c/o Postmaster, San Francisco, Calif.

Capt. JOHN M. GOLDEN is now serving with the 1265th Engr. Combat Bn., Camp Van Dorn, Miss.

THOMAS J. ETHERINGTON has returned to the States from the Richmond Petroleum Co. of Colombia, Bogota, Colombia, and is located at 3163 W. Laurelhurst Drive, Seattle, Wash.

JOHN CARR, who joined the Society while on duty with the Shell Co. of Australia, has been transferred to the Shell Co. of Egypt, Cairo, Egypt.

JAMES A. LONG is located in Green River, Wyoming, where his postal address is Box 71.

ROBERT J. MCGANN, of the Western Geophysical Co., has been transferred from Los Banos to Bakersfield, Calif., where his address is 3530 Chester Ave.

A. A. HUNZICKER, of the Texas Co., has changed his mailing address from Box 32, Nashville, Ill., to Box 2332, Houston 1, Texas.

Notification has been received of L. J. SMITH'S change of address from Box 476, Centralia, Ill., to 411 South Fourth St., Neodesha, Kansas.

JOHN L. BIBLE has resigned as Supervisor of the Gravity and Magnetic Departments of the Stanolind Oil and Gas Company to become Executive Vice-President of the North American Geophysical Company, which is engaged in seismic and gravity surveys and the manufacture of geophysical instruments.

ROBERT E. FEARON has resigned his position as Research Physicist in the Research Department of the Stanolind Oil and Gas Company to set up as a consulting engineer and geophysicist, with offices at 909 Tulsa Loan Building, Tulsa, Oklahoma.

SAINT LOUIS UNIVERSITY, at 221 North Grand Boulevard, Saint Louis, Missouri, has organized an INSTITUTE OF GEOPHYSICAL TECHNOLOGY, with JAMES B. MACELWANE, S.J., as Dean. Four year courses are offered leading to degrees in PETROLEUM GEOPHYSICS, MINING GEOPHYSICS, SEISMOLOGICAL ENGINEERING, GEOLOGICAL ENGINEERING, RADIO COMMUNICATIONS ENGINEERING, APPLIED ELECTRONICS, and PROFESSIONAL METEOROLOGY. Further information concerning the new institute can be secured by addressing the Dean.